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THE USE OF THE CREW SIZE EVALUATION METHOD TO EXAMINE THE EFFECT OF OPERATIONAL FACTORS ON CREW NEEDS

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16. Abstract (MAXIMUM 200 WORDS)

The Crew Size Evaluation Method (CSEM) is a task-based approach to determining crew size on commercial ships. CSEM was used to examine the effects of three factors on crew needs: port call frequency, shoreside maintenance support, and three different sets of work/rest standards (U.S. Oil Pollution Act of 1990 (OPA '90); Seafarers' Training, Certification, and Watchkeeping Code (STCW); and International Labor Organization Convention 180 (ILO 180)). The analyses identified how these changes resulted in differing needs for particular crew types and shipboard tasks. This demonstrates CSEM's ability to clarify how different operational scenarios impact crew needs and to aid in determining how to redistribute tasks to other crew members or add additional crew in order to avoid overloading particular crew members.

This is one of two reports on the use of CSEM to evaluate crew needs under different operational scenarios. This report contains a detailed description of how CSEM is used to analyze scenarios and discusses several criteria, which can be applied in the evaluation of sufficient crew. A related paper, "Simplified Crew Size Evaluation Method," CG-D-13-00, explains how the full-scale analyses from CSEM can be packaged into simple lookup tables, yielding a quick and practical tool for crew size evaluation.

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Executive Summary

The Crew Size Evaluation Method (CSEM) is a task-based approach to determining crew size on commercial ships. CSEM simulates a voyage by scheduling the shipboard tasks which must be performed during each phase of the voyage (open waters, restricted waters, and in port), and assigns appropriate crew members to each task. CSEM records the number of hours worked by each crew member over each day of the voyage and tracks tasks that were delayed due to crew unavailability. This gives CSEM the capability to compare the effects of different operational factors on the number of crew needed to perform all tasks without exceeding work-hour limits (such as those mandated by OPA '90). This report examines the effects of three factors: port call frequency, shoreside maintenance support, and three different sets of work/rest standards (OPA '90, STCW, and ILO 180).

The effect of port call frequency was studied. Three different voyage scenarios used by United States (US) tankers with different port call frequencies were compared: one port call in 14 days, 3 in 14, and 7 in 14. As the number of port calls increases, there are increasing numbers of hours required for restricted waters transit, line handling, and cargo transfer operations. The CSEM analyses indicated a direct relationship between increased port call frequency and increased crew tasking. This would indicate a need for crew workload relief or adding crew members to accommodate the higher tasking levels.

The use of shore-based maintenance support has received interest as a possible means of reducing the amount of maintenance required by the ship's crew, thereby reducing the size of the crew. Three shipping companies were interviewed as to the types of shoreside maintenance support they currently receive, and what types of support they might contemplate in the future. Four levels of maintenance support were considered; under the lowest level, almost no shoreside assistance is received, while under the highest level, almost all the maintenance and repair tasks were assumed to be performed by shore-based personnel. It was found that for a vessel with a fully-attended engine room, watchkeeping operations far outweigh maintenance tasks as the

driver of crew size. CSEM indicated that the highest level of shoreside maintenance and repair did not reduce engine room crew complements.

In the final analysis, three work/rest standards were compared: OPA '90, STCW, and ILO 180. When the work-hour limits of OPA '90 are combined with either or both of the other two standards, it resulted in an increase in the number of times crew members exceeded the work-hour limits. However, combining the standards was not seen to reduce the work hours for the crew. This reflects the relatively large number of high priority tasks which cannot be delayed, and suggests that these tasks will be performed even when it results in crew members exceeding the work/rest standards.

It is important to note that CSEM and the analyses reported here make several assumptions about shipboard organization and procedures which may not match actual operations on every ship. The analyses reported here were based on operational and task data collected on three tankships. From these data we abstracted "typical" rules which the CSEM model uses to prioritize shipboard tasks, to assign crew to those tasks, and to manage crew work hours so as to avoid exceeding work-hour limits. To the extent that a given ship operates differently from these assumptions, the specific crew size that a vessel may need may differ from those shown in our analyses. However, the *trends* shown in the analyses (i.e., increasing or decreasing work hours as a function of a given operational factor) will be valid for all ships.

These analyses demonstrate the ability of CSEM to analyze the effects of different maritime operational factors and regulations on crew size and crew work hours. CSEM is a flexible and powerful tool which can be used to understand what crew types and what shipboard tasks are most affected by changes in operations. Thus, it can be used to educate the industry on the crew size implications of certain operations, and it can help to anticipate the effects of potential regulatory changes.

A related paper, "Simplified Crew Size Evaluation Method," CG-D-13-00, explains how the full-scale analyses from CSEM can be packaged into simple lookup tables, yielding a quick and practical tool for crew size evaluation.

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List of Abbreviations

AB	Able-Bodied seaman
AE	Assistant Engineer
B	Boatswain
COI	Certificate of Inspection
CE	Chief Engineer
C	Cooks
CSEM	Crew Size Evaluation Method
ILO	International Labor Organization
IMO	International Maritime Organization
MA	Master
M	Mates
MSO	Marine Safety Office
OPA '90	Oil Pollution Act of 1990
PM	Pumpmen
QMED	Qualified Member of the Engineering Department
STCW	Seafarer's Training, Certification, and Watchkeeping
U	Utility persons

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1.0 Introduction

1.1 Background and Purpose

Accurate evaluation of crew needs is a critical issue that has major safety implications. Excessive fatigue, and its effect on safe operations, is one consequence of an inadequate crew (Sanquist, Raby, Maloney, & Carvalhais, 1996). The wide variety of shipboard activities and operational conditions makes an accurate evaluation of crew needs difficult. To address this difficulty we have developed a task-based method for evaluating crew size: the Crew Size Evaluation Method (CSEM; Lee, McCallum, Maloney, & Jamieson, 1997). This approach evaluates crew needs by examining the time demands of the tasks crew members must perform aboard ship. The purpose of this report is to demonstrate how this task-based analysis of crew needs can resolve a range of crew size issues.

Crew size evaluation is a pervasive issue that confronts the Coast Guard in several ways (Lee, McCallum, Maloney, & Jamieson, 1997; NRC, 1990). Crew size issues arise in the development of domestic and international standards and practices, in routine certification of vessels, and in shipping company requests for certificate of inspection (COI) revisions. CSEM has the flexibility to support the analysis of a variety of operational factors and practices and can help the Coast Guard and industry to understand how these factors affect the crew complement needed for safe operation. To coordinate U.S. policy with the international maritime community, the effects of international agreements on crew complements need to be anticipated. CSEM can examine the effects of candidate standards before they are adopted. In negotiations with shipping companies to resolve unusual crewing requests, the lack of a definitive technical basis can hinder decision making. CSEM can help resolve these ambiguities by providing supporting analysis. More generally, CSEM clarifies how a wide variety of operational factors affect the number and type of crew members needed to operate a ship safely. In summary, using a task-based approach, CSEM can support:

- Coast Guard and industry education and understanding of factors affecting crew size.
- Coast Guard representatives to the International Maritime Organization (IMO) in anticipating the implications of international agreements.
- Coast Guard headquarters personnel in evaluating unusual crewing requests.

The complexity of CSEM makes direct application to these objectives impractical. Instead, analyses will be done by a specialist and the results will be disseminated in a summarized form. This report illustrates three such analyses.

1.2 Issues Selected for Analysis

Collaboration with Coast Guard Headquarters personnel (G-MSO-1) identified three critical issues that represent typical questions regarding crew needs. The first issue concerns the effect of port calls on crew workload and associated crew needs. The second issue concerns how shore-based maintenance workers might perform maintenance tasks assigned to the crew, and whether or not this would reduce workload and overall crew needs. The third issue concerns work/rest standards and how compliance with different standards affects crewing. The analyses generate three outcomes. First, they demonstrate the range of CSEM's capabilities. Second, the analyses provide insight into critical crew size issues by identifying factors that have an important influence on crew needs. Third, the analyses show how a specialist can conduct analyses with CSEM and then summarize and disseminate the results to MSOs, headquarters personnel, and members of IMO. Overall, these analyses demonstrate the current capabilities of CSEM and show how it might be used in the future.

1.3 Selection of Representative Analysis Conditions

Selecting representative analysis conditions is a critical first step in any analysis. To generalize operational conditions successfully, the analysis should consider conditions that are representative of actual situations. To identify representative conditions, we performed an informal survey of shipping companies. Appendix A contains the detailed results of this survey.

This survey identified typical operating conditions of commercial ships. Port call frequency and maintenance practices are conditions of particular interest.

The results of this survey identified a representative ship, which was then used as a baseline condition in the analyses. This representative ship has the following characteristics:

- Crude oil tanker.
- Age of approximately 20 years.
- Cargo capacity of approximately 950,000 barrels.
- Steam turbine power plant.

1.4 Measures for Crew Size Evaluation

The goal of the analyses is to identify how operational factors affect crew needs. Achieving this goal requires that the output of CSEM be summarized in a way that accurately captures the influence of operational variables on vessel safety. Vessel safety can be defined as the ability of a crew to perform shipboard tasks in a timely manner, while receiving adequate rest. Four general categories of measures address timely task performance and mariner work/rest patterns:

- Hours worked and slept.
- Time crew members are busy performing tasks.
- Nonconformance with work/rest standards.
- Task delays.

The hours worked by crew members include the normally scheduled periods on duty and any overtime work. The hours that crew members are working limits the time they have to sleep. CSEM estimates the time available to sleep as the hours not spent working, eating, or preparing

to work.[1] The time crew members are busy performing tasks estimates the amount of time crew members spend working on all non-watchstanding activities. Nonconformance with work/rest standards identify when individuals have exceeded work-hour limits or have not been given sufficient rest periods. The analysis of port call frequency and level of shore-based maintenance use the Oil Pollution Act of 1990 (OPA '90) work-hour limits to calculate days in which work-hour limits were exceeded. In addition to OPA '90, the analysis of work/rest standards includes maximum work and minimum rest hours as defined by the International Labor Organization's convention 180 (ILO 180) and the IMO's Seafarer's Training, Certification, and Watchkeeping (STCW) Code. (Appendix B contains a detailed description of the calculation of work/rest standard nonconformance.) The final category of measures is task delay, which is the time a task must wait because crew members are not available to perform it. These four general measurement categories represent important elements of ship operations and support a comprehensive analysis of the crew complement.

Many specific measures can be identified in each of these general categories. Most simply, these include the mean number of hours of work or sleep in each 24-hour period. More complicated measures include the percentage of days in which a crew member works more than 18 hours. The specific measures can be divided into two categories: measures that address *chronic* problems that persist over several days, and those that address *acute* problems that are associated with peak demands. The mean number of work hours in each 24-hour period reflects chronic overload (if the mean is greater than the 12 hr/day OPA '90 permit), and the percentage of days in which a crew member worked more than 18 hours reflects acute overload. More than 18 hours of work and less than four hours of sleep were chosen as critical levels of crew overload based on research that shows declines in human performance under these conditions (U.S. Department of the Army, 1985). However, specific thresholds are difficult to define due to the range and variability of the effect of sleep loss on performance (Bartlett, 1943; Craig and Cooper, 1992). Table 1 defines 12 potential measures of acute and chronic overload that might be used to evaluate a crew complement.

[1] Time available for sleep may overestimate the actual amount of sleep mariners receive because it does not account for personal time (recreation, laundry, letter-writing, etc), nor does it account for physiological factors, such as circadian rhythms, that make sleep at certain times of the day difficult (Sanquist, Raby, Maloney, Carvalhais, 1996).

Table 1. Potential Measures of Crew Overload.

Potential measures	Type of Overload	Definition
Work	Chronic	Mean number of hours worked each day.
STD Work	Acute	Standard deviation of hours worked each day.
WGTE18	Acute	Percentage of days with 18 or more hours of work.
Sleep	Chronic	Mean number of hours available for sleep each day.
STD Sleep	Acute	Standard deviation of hours slept each day.
SLTE4	Acute	Percentage of days with four hours of sleep or less.
Busy	Chronic	Mean number of minutes occupied on a specific non-watch task each day.
STD Busy	Acute	Standard deviation of minutes occupied on a specific non-watch task each day.
OPA90	Chronic	Mean number of crew exceeding OPA '90 each day.
D_OPA90	Acute	Percentage of days with one or more crew exceeding OPA '90.
STD OPA90	Acute	Standard deviation of crew exceeding of OPA '90 each day.
Delay	Chronic	Mean number of minutes tasks were delayed.

Using all 12 measures to evaluate a potential crew would be impractical and statistically inappropriate. Ideally, crew size should be evaluated with only the variables needed to describe the situation; otherwise the correlation between variables and the number of comparisons will undermine the validity of statistical tests. This implies a selection of a subset of the 12 variables that are relatively independent, but which describe the variations of the entire group of variables. Table 2 shows the correlation between the 12 variables. The correlations and subsequent factor analyses were based on data from all three analyses (Port calls, Shore-based maintenance, and Work/rest standards). These data represent over 20,000 person-days of shipboard activity.

Table 2 shows that many of these variables are highly correlated and do not represent independent measures of the crew. For example, the standard deviation of hours worked each day (STD Work) has a high correlation (0.724, as shown in column 2 row 6 of Table 2) with the percentage of days with four hours of sleep or less (SLTE4). What this means is that both variables are measuring a similar underlying factor, fluctuations in day-to-day work and rest times. As the amount of time worked increases, the amount of time available for rest decreases, and the likelihood of getting no more than four hours of rest increases. In essence these two

variables have, to a large degree, the same underlying structure. Thus, we would not include both these variables as measures of crew overload, since one can pretty much represent the other. Instead we would want to find additional measures which are relatively uncorrelated with either of these (such as Delay).

Table 2. The Correlation between 12 Potential Measures of Crew Overload.

Variable	1	2	3	4	5	6	7	8	9	10	11	12
1) Work	1	.394	.448	-.587	.211	.387	.595	.314	.698	.751	.665	-.157
2) STD Work	.394	1	.793	-.447	.799	.724	.363	.871	.279	.341	.355	.019
3) WGTE18	.448	.793	1	-.500	.646	.711	.332	.750	.258	.297	.255	-.113
4) Sleep	-.587	-.447	-.500	1	-.249	-.604	-.250	-.430	-.336	-.367	-.388	.362
5) STD Sleep	.211	.799	.646	-.249	1	.758	.272	.670	.160	.185	.200	.073
6) SLTE4	.387	.724	.711	-.604	.758	1	.276	.645	.232	.264	.288	-.135
7) Busy	.595	.363	.332	-.250	.272	.276	1	.302	.305	.345	.302	.117
8) STD Busy	.314	.871	.750	-.430	.272	.645	.302	1	.189	.241	.253	-.045
9) OPA90	.698	.279	.258	-.336	.160	.232	.305	.189	1	.955	.788	-.018
10) D_OPA90	.751	.341	.297	-.367	.185	.264	.345	.241	.955	1	.823	-.051
11) STD OPA90	.665	.355	.255	-.388	.200	.288	.302	.253	.788	.823	1	-.073
12) Delay	-.157	.019	-.113	.362	.073	-.135	.117	-.045	-.018	-.051	-.073	1

A factor analysis is a statistical method used to examine the structure underlying the correlation between a group of variables and to identify a subset of relatively independent variables that describe the entire group. A factor analysis* was performed on the variables in Table 2 and revealed four factors which account for 82.5 percent of the variance of the 12 variables. Table 3 summarizes the factor analysis by showing the correlation of the twelve potential measures with each of the four factors.

* The factor analysis used an eigenvalue cutoff of 0.75 followed by a Varimax rotation.

Table 3. The Correlation between Each Rotated Factor and the 12 Potential Measures of Crew Overload.

Variable	Factor 1 (Workload fluctuations)	Factor 2 (Nonconformance of work/rest standards)	Factor 3 (Task delay)	Factor 4 (Non-watch workload)
1) Work	.211	.680	-.283	.546
2) SD_Work	.917	.215	.024	.124
3) WGTE18	**.833**	.152	-.176	.185
4) Sleep	-.407	-.294	.653	-.252
5) SD_Sleep	.860	.092	.159	.018
6) SLTE4	.803	.162	-.229	.099
7) Busy	.211	.205	.091	**.915**
8) SD_Busy	.894	.101	-.055	.097
9) OPA90	.093	.953	-.013	.089
10) D_OPA90	.132	**.956**	-.044	.127
11) SD_OPA90	.153	.891	-.074	.071
12) Delay	.013	-.065	**.895**	.134

Table 3 shows that most variables are linked to one of the four factors in an orderly manner. For example, the standard deviation of time spent on non-watchstanding tasks (SD_Busy), the percent of days with more than 18 hours of work (WGTE18), the standard deviation of hours spent working (SD_Work), and the percent of days with less than four hours available for sleep (SLTE4) are all highly correlated with the first factor and are logically similar; these four variables all reflect overloads associated with extreme fluctuations in workload. Similarly, the number of crew who exceed the OPA '90 work-hour limit per day (OPA90), the standard deviation of the OPA excesses per day (SD_OPA90), and the percent of days a crew member exceeded OPA '90 (D OPA90) are all highly correlated with the second factor and are logically related. These three variables reflect work hours over the work/rest standards. The third factor is most highly correlated with task delays (Delay), reflecting situations that lead to overloads and disrupt tasks. The fourth factor is highly correlated with the time spent busy with non-watchstanding tasks (Busy) and reflects non-watchstanding workload. The clear and logical

relationship between the factors and variables suggests that the four factors accurately describe the essence of the 12 variables.

The factors in Table 3 provide a useful tool for selecting measures of crew needs. Each factor can identify a set of minimally correlated variables that capture the essence of the CSEM output. By choosing a variable that is highly correlated with each factor, the variable can act as a surrogate for that factor and will be relatively uncorrelated with variables chosen as surrogates for each of the other factors. Using this rationale, WGTE18, Busy, D_OPA90, and Delay were chosen as surrogates for the four factors. WGTE18 was chosen instead of SD_Busy or SD_Work because it is a more concrete and intuitive variable. The mean hours worked (Work) was also selected as a measure because it provides an easily understood description of crew activity and because it is one of the primary variables in estimating compliance with work/rest standards and managing shipboard activity. However, Work is not a surrogate for one of the four factors and so is highly correlated with some of these measures. Table 4 shows the correlations between these five measures of crew overload. Although several of the surrogate measures have a moderate correlation, none exceeds 0.35. Because Work was chosen independently of the factor analysis, it is correlated with some of the measures. In particular, Work is highly dependent on the percent of days in which OPA '90 was exceeded (D_OPA90).

Table 4. The Correlation between Five Measures of Crew Overload.

Variable	1	2	3	4	5
1) Work	**1**	**.448**	**.595**	**.751**	**-.157**
2) WGTE18	**.448**	1	.332	.297	-.113
3) Busy	**.595**	.332	1	.345	.117
4) D_OPA90	**.751**	.297	.345	1	-.051
5) Delay	**-.157**	-.113	.117	-.051	1

For each of these measures, specific decision criteria are needed to identify an inadequate crew. Decision criteria specify thresholds that identify the need for more crew members. These criteria must address *chronic* problems that persist over several days, as well as *acute* problems that are

associated with peak demands. For this analysis, the measures used to identify chronic overload associated with an inadequate crew include:

- Average hours worked each day, with the criterion of ≥ 13 hours per day.
- Time busy performing non-watchstanding tasks.
- Average task delay each day.

The measures used to identify acute overload focus on extremely long workdays (greater than 18 hours) and workdays in excess of the OPA '90 work-hour limits. The specific measures for acute overload include:

- Work exceeds 18 hours a day, with the criterion of more than 10 percent of the days of a voyage.
- The percentage of days in which OPA '90 was exceeded.

Specific criteria for task delays, percentage of days which exceed OPA '90, and time that the crew is busy performing non-watchstanding tasks were not identified. These variables depend on crew position. As an example, watchstanders tend to spend far more time watchstanding than on other tasks. For this reason, task delay, OPA '90 excesses, and time busy data were used only to complement the criteria of average hours worked and the percentage of extremely long workdays.

Defining decision criteria for adding crew members for each measure remains an important issue for future consideration. For this report the criteria of more than an average of 13 hours of work per day was adopted to reflect excessive levels of chronic workload. This criterion was chosen because OPA '90 limits mariners to 36 hours of work in a 72-hour period (nominally 12 hours per day); thus, exceeding 13 hours per day on average represents a regularly occurring work-hour overage. The criterion of more than 10 percent of days with over 18 hours of work was chosen because 10 percent represents a prevalent occurrence of acute overload and undermines the crew members' ability to recover from long work days. These criteria are suggestions, and their precise values merit thoughtful refinement. However, the measures and

criteria proposed are logical starting points and may be used profitably to observe the acute and chronic consequences of operational variables (like port call frequency and shoreside maintenance) on shipboard work activity.

1.5 General Method of Analysis

The analysis of each operational factor is based on the data provided by CSEM's simulation of a 14-day voyage. The input to the simulation includes a voyage profile, crew complement, and task assignments. The voyage profile defines the timing and duration of port calls. The crew complement identifies the number, type, and work schedule of the crew members. The task assignments identify the type of crew needed to perform each task, the frequency with which each task must be performed, and the time required to perform the task. Appendix C shows the detailed task assignments used in the analysis. The results of the analyses apply to situations that are similar to the one described in Appendix C.

Analysis of each operational factor was conducted by comparing the effect of different levels of the operational factor, such as port call frequency, to a baseline condition. For each level of the operational factor the simulation was run seven times. Each run simulates shipboard activity for a 14-day voyage, and was identical with the exception of the random number seed. The random number seed defines the stream of random numbers that are selected for the various task duration and task interval distributions. CSEM randomly generates a different random seed for each of the seven simulation runs. Each analysis was conducted with a baseline crew and the need for additional crew was identified using the criteria discussed above.

It is important to note that CSEM and the analyses reported here make several assumptions about shipboard organization and procedures which may not match actual operations on every ship. The commercial maritime industry is marked by variety: different companies and different vessel types are apt to have variations in their on-board organization and operational strategies. The analyses reported here were based on operational and task data collected on three tankships. From these data we abstracted: 1) "typical" task requirements, e.g., the time required to perform a given task and the crew member(s) typically assigned (as shown in Appendix C); and

2) "typical" rules which the CSEM model uses to prioritize shipboard tasks, to assign crew to those tasks, and to manage crew work hours so as to avoid exceeding work-hour limits (for details on the data and assumptions which underlie CSEM, please see Lee, McCallum, Maloney and Jamieson, (1997)). To the extent that a given ship operates differently from these assumptions, the specific crew size that a vessel may need may differ from those shown in our analyses. However, the *trends* shown in the analyses (i.e., increasing or decreasing work hours as a function of a given operational factor) will be valid for all ships.

1.6 Format of Analysis Summaries

A consistent format summarizes each analysis. The summary begins with a short paragraph describing the *background* of the issue and why the analysis is important. A description of the *test scenarios* identifies the range of operational factors addressed. A description of *limits and assumptions* places bounds on how the analysis can be interpreted and used. Several tables and graphs summarize the *findings* and show how the criteria are applied to evaluate the proposed crew complement.[2] Each analysis concludes with *conclusions* that draw practical guidance from the findings.

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[2] A 0.05 family-wise level of significance was chosen and a Bonferroni adjustment was used to account for the simultaneous assessment of five measures (Stevens, 1996).

2.0 Analysis of Port Call Frequency

2.1 Port Call Frequency: Background

The demands of cargo operations, navigation, and line handling make it likely that increasing port call frequency will increase the workload of the crew. This increased workload may increase the number of crew members needed to operate the ship safely. The Marine Safety Manual does not provide specific guidance for how crew complements should be adjusted to account for this increased workload. To address this lack of guidance, CSEM can assess the effect of port calls on workload and associated crew needs and augment the guidance in the Marine Safety Manual.

2.2 Port Call Frequency: Baseline and Test Scenarios

An industry survey identified a representative range of port call frequencies. Table 5 summarizes three typical port call frequencies and the associated voyages. The duration of restricted waters transit and port calls varies considerably for the different levels of port call frequency. Table 5 shows that the number of hours spent in port each day, averaged over the entire voyage, is greatest for the high port call frequency. Because of the long restricted waters transit associated with Valdez, Alaska, and Cherry Point, Washington, the average number of hours in restricted waters is greatest for the medium level of port call frequency. The scenarios used in the analysis assume that the port calls are equally spaced, with the same number of days between each port call. Unequally spaced port calls will accentuate workload peaks, and additional time in restricted waters would also increase workload. Each port call involves either the loading or discharge of cargo. Therefore, more frequent port calls are expected to increase workload through additional cargo handling demands, line handling, and restricted waters transit.

The baseline scenario consists of three port calls, and is shown in the second row of Table 5. The crew complement for this baseline condition includes a total of 24 people:

- Master
- 3 Mates
- Day-working Boatswain
- 6 ABs
- Utility
- Chief Engineer
- 3 Assistant Engineers
- 3 Qualified Members of the Engineering Department
- 2 Pumpmen
- Chief Steward
- 2 Cooks

Table 5. Three Levels of Port Call Frequency and Prototypical Voyage for Each.

Port Call Frequency	Port Calls in 14 Days	Voyage Profile	Time in Port	Time in Restricted Waters	Time at Sea	At Sea Operations
High	7	Estero Bay, CA to El Segundo, CA	1 day 14 hr avg/day*	1 hr/port call 1 hr avg/day	18 hr 9 hr avg/day	Cargo and ballast maintenance and monitoring
Medium	3	Valdez, AK to Cherry Point, WA	1 day 5 hr avg/day	14 hr/port call 4 hr avg/day	4 day 15 hr avg/day	Cargo and ballast maintenance and monitoring, vessel fabric mainte-nance
Low	1	Houston, TX to Richmond, CA	2 day 5.14 hr avg/day	4 day (Panama Canal) 0.86 hr avg/day	10 day 18 hr avg/day	Cargo and ballast maintenance and monitoring, vessel fabric mainte-nance, tank cleaning

* "Hr avg/day" represents the total amount of time spent (in port, in restricted waters, or at sea) averaged over the 14 days of the voyage.

2.3 Port Call Frequency: Limits and Assumptions

The validity of the analysis results rests on several important assumptions. These assumptions should be considered when interpreting the findings. Most importantly, the analyses are based on a baseline vessel with task assignments described in Appendix C. A different set of task assignments might produce different results. Another important assumption is that the evaluation criteria are reasonable; changing the criteria may change the crew needs. The final two assumptions reflect the distribution and amount of work. We assume that port calls are equally spaced, which minimizes workload peaks. We also assume that each port call involves

extensive cargo transfer which results in a substantial load on the crew members. A different distribution of port calls or amount of cargo transfer could change the distribution of work and the number of crew needed.

In summary, some important limits and assumptions of this analysis include:

- Characteristics of particular ships might influence these results. For example, automatic line tensioning and cargo handling equipment could reduce some of the demands of port calls.
- Changing the criteria used to evaluate a crew might influence the crew size evaluation.
- The port calls are equally spaced. Unequal spacing would give crew members less time to recover during the open water segments of the voyage.
- Each port call involves extensive cargo transfer. Port calls that involve less cargo operations would place smaller demands on the crew.

2.4 Port Call Frequency: Findings

Table 6 shows how crew needs change with different port call frequencies. Very infrequent port calls eliminate the need for a shore-based loading Mate. Frequent port calls demand another Mate to relieve the Chief Mate from watchstanding duties, and an able-bodied seaman (AB) to assist with cargo operations and line handling.

Table 6. Change in Crew Needs with Different Port Call Frequencies.

Port Calls	Ship's Crew	Change from Baseline	Shoreside Loading Mate
7 in 14 days	26	Add one Mate and one AB	Yes
3 in 14 days (Baseline)	24	None	Yes
1 in 14 days	24	Subtract loading Mate	No

A statistical analysis of variance (ANOVA*) was performed to look at the relationships between port call frequencies, crew types, and the five measures of shipboard activity or crew overload:

- Work, the mean number of hours worked each day;
- WGTE18, the percentage of days with ≥ 18 hours of work;
- Busy, the mean time worked on non-watch tasks each day
- D_OPA90, the percentage of days in which one or more crew members worked more than the OPA '90 work-hour limit;
- Delay, the mean time tasks were delayed each day.

The variables Work, WGTE18, Busy, and D_OPA90 showed a significant effect of port call frequency; that is, the different port call frequencies resulted in different levels of crew activity and overload. Task delay did not show this effect. There was a strong interaction effect which indicates that the influence of port call frequency is not uniform across the crew. For example, port call frequency has a relatively small effect on Utility persons, but a large effect on the Mates and ABs.

Figure 1 shows the criterion used to identify additional crew needs due to chronic overload. Additional crew members are needed if a crew member exceeds an average of 13 hours a day. The overall crew averages are shown as gray bars and the average for individual crew types are shown as lines. For this analysis, crew types were defined as Master (MA), Mates (M), Able-Bodied Seamen (ABs), Chief Engineer (CE), Assistant Engineers (AE), Qualified Members of the Engineering Department (Q), Pumpmen (PM), Utility Persons (U), Cooks (C), and Boatswain (B). More frequent port calls result in longer work hours and less sleep, for the overall crew (shown by the bars) and for the ABs and Mates in particular. Specifically, the Mates and some of the ABs work an average of more than 13 hours each day, although the average for all six ABs was 12.2 hours per day (in the high port call frequency condition of 7 ports in 14 days). Both the ABs and Mates see an increase in work hours per day of 1.5 to 2.0 hours from the low to the high port call frequency. Accordingly, the high port call frequency shows chronic overwork of the Mates and some ABs, requiring some additional personnel.

* The ANOVA table is provided in Appendix D.

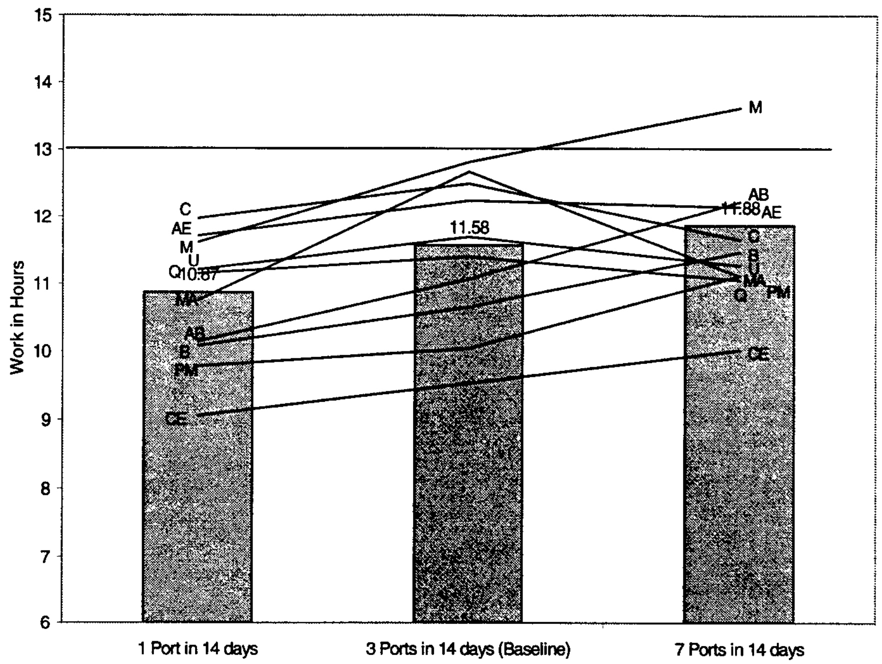


Figure 1. The Average Hours of Work Each Day for Three Port Call Frequencies.

Figure 2 shows that increasing the frequency of port calls increases the number of acute overload periods. Specifically, the overall crew experiences an increase in the number of 18-hour workdays, and for some crew types the effect is more dramatic. The Mates and some of the ABs see the largest increase in the number of 18-hour days, with their total exceeding 10 percent when there are seven port calls in 14 days. In this situation, the Mates are likely to experience one or two 18-hour days in a 10-day period. This demonstrates the need for an additional Mate due to acute overload. The Master's workload is high in the second scenario due to the duration of restricted waters passages, which are the longest in the baseline conditions. In contrast, the line handling and cargo operations are the primary contributors to the increase in the Mates' workload, and are highest in the third condition.

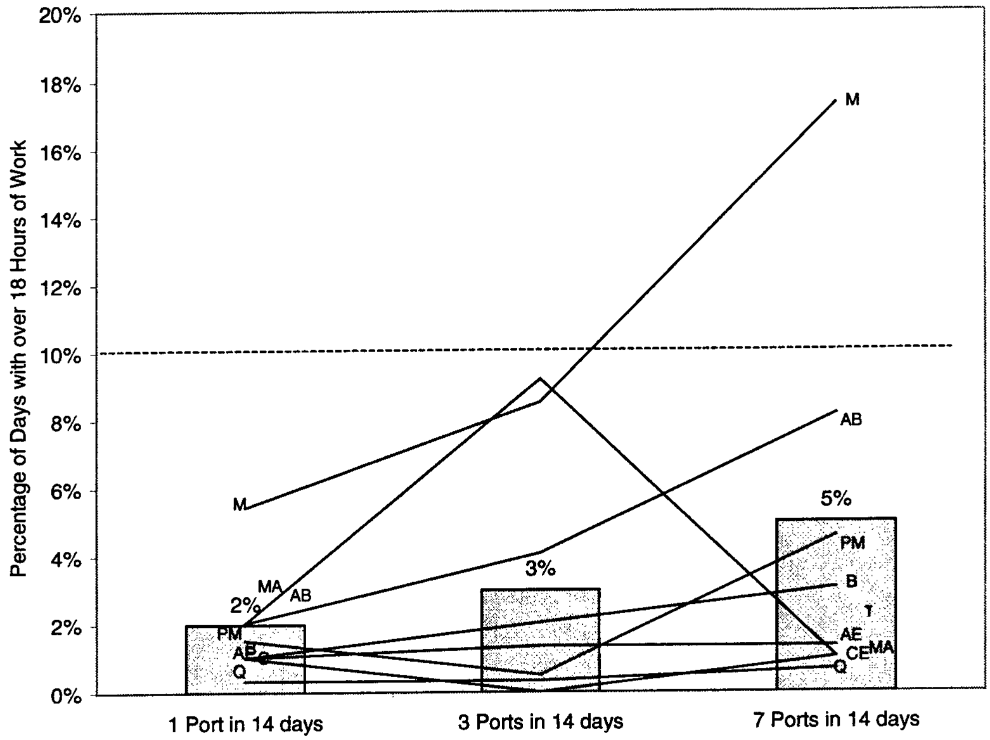


Figure 2. The Percentage of Days with More than 18 Hours of Work for Three Port Call Frequencies.

Figure 3 shows the average number of minutes of non-watchstanding tasks that occupy crew members each day. The wide variation reflects the different crew positions: non-watchstanders are often busy on non-watchstanding tasks. The peak for the Master in Figures 2 and 3 reflects the Master's oversight responsibilities during restricted waters transit. The baseline condition (3 ports in 14 days) has a greater number of hours of restricted waters transit than the other conditions.

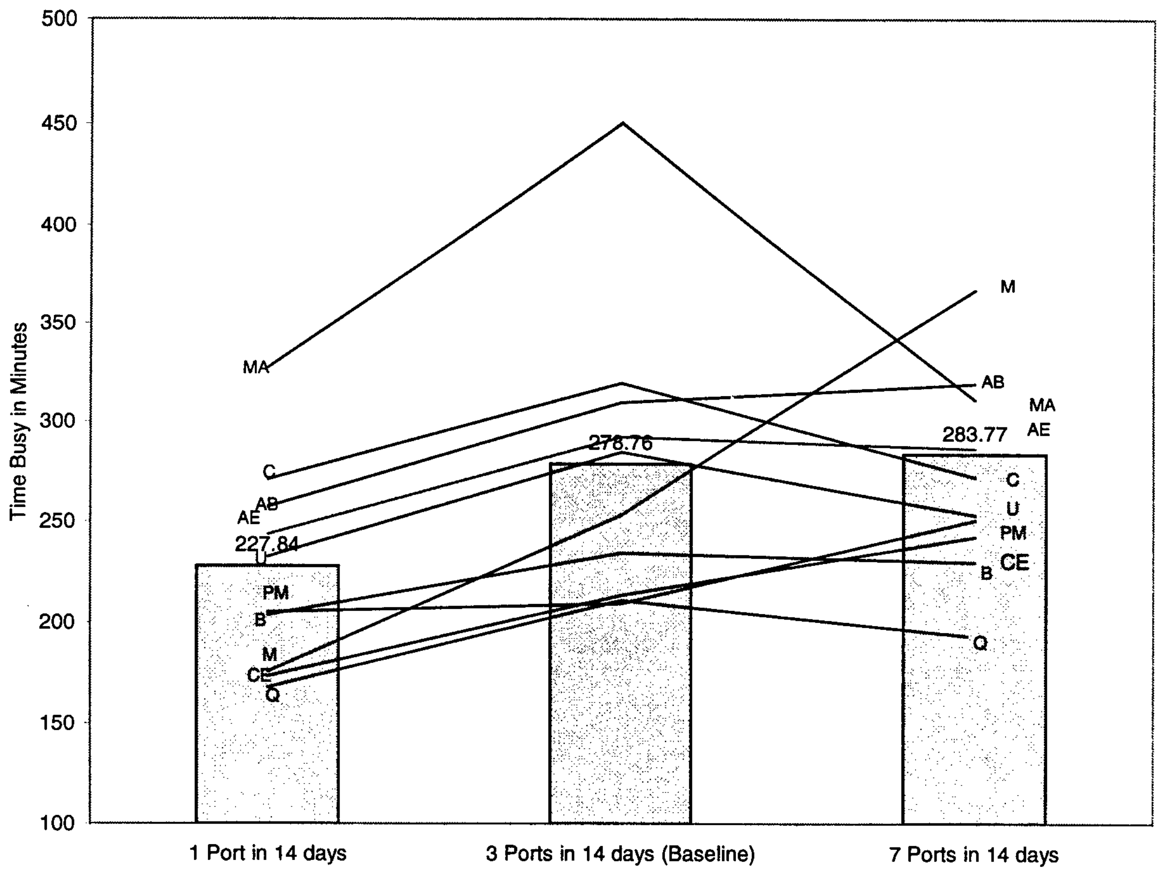


Figure 3. The Average Time Busy with Non-watchstanding Tasks for Three Port Call Frequencies.

Figure 4 shows the distribution of OPA '90 nonconformances where a crew member has exceeded the OPA '90 limits at any time during the day. This distribution shows a pattern similar to the other variables: nonconformity increases dramatically for the Mates, ABs, and Pumpmen as the frequency of port calls increases, whereas other crew types, such as engineers, are relatively unaffected by port call frequency, but still have a large number of nonconformities. As an example, the AEs show a consistently high number of nonconformities. This reflects their consistently long work days which seldom drop below 12 hours per day. Figure 4 also shows that working slightly more than 12 hours per day results in a high number of work-hour overages, with AEs exceeding work-hour limits more than 50 percent of the time while working about 12 hours per day. As with the average work hours, Figure 4 also shows that the Master experiences a higher number of nonconformities in the second condition due to the large number of hours spent on restricted waters.

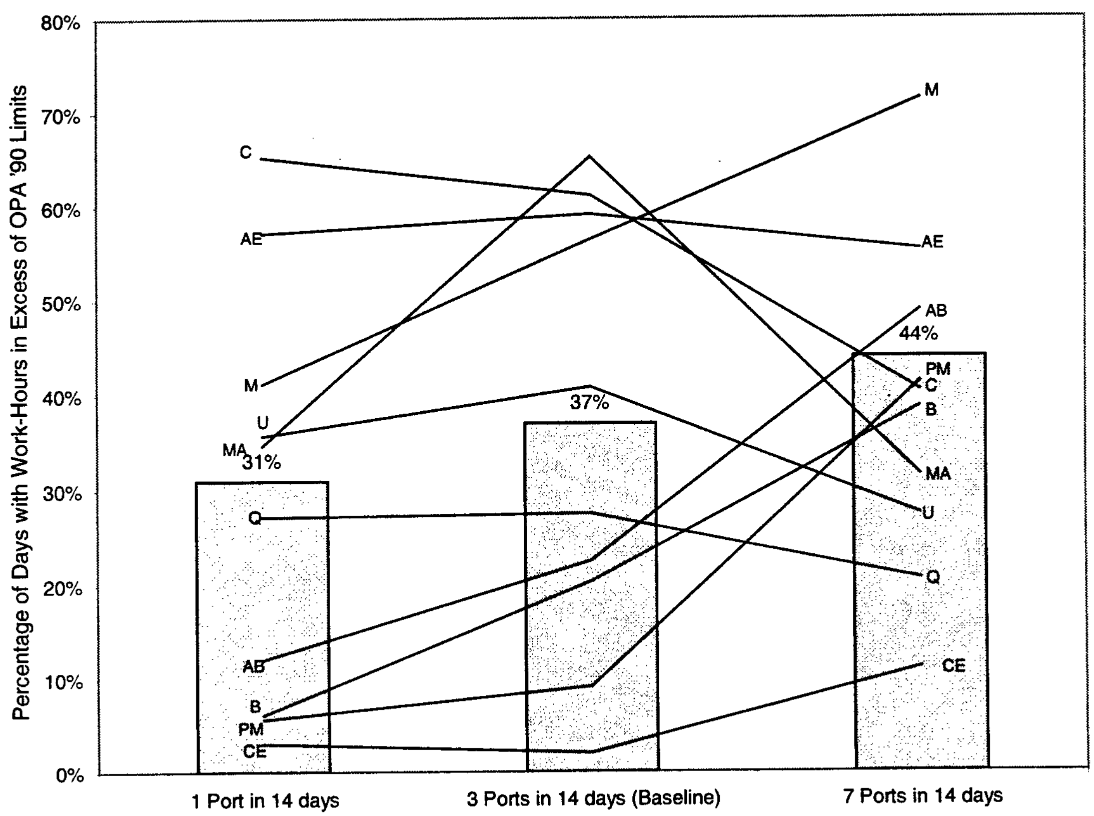


Figure 4. The Percentage of Days which Exceed OPA '90 for Three Port Call Frequencies.

Because a large number of tasks are artificially suspended at each port call, the task delay information in Figure 5 does not reflect changing work demands, but rather is an artifact of the simulation approach. Task delays are not a useful measure of crew workload when voyage segments are substantially different sizes, as is the case for different port call frequencies. The reason for this has to do with how the simulation handles tasks: tasks that do not occur in the next voyage segment are purged from the event queue. This means that when CSEM simulates a scenario with many port calls and short voyage segments, it will purge tasks repeatedly, preventing them from accumulating a large delay. Furthermore, the average task delay across the three levels of port call frequency is not statistically different.

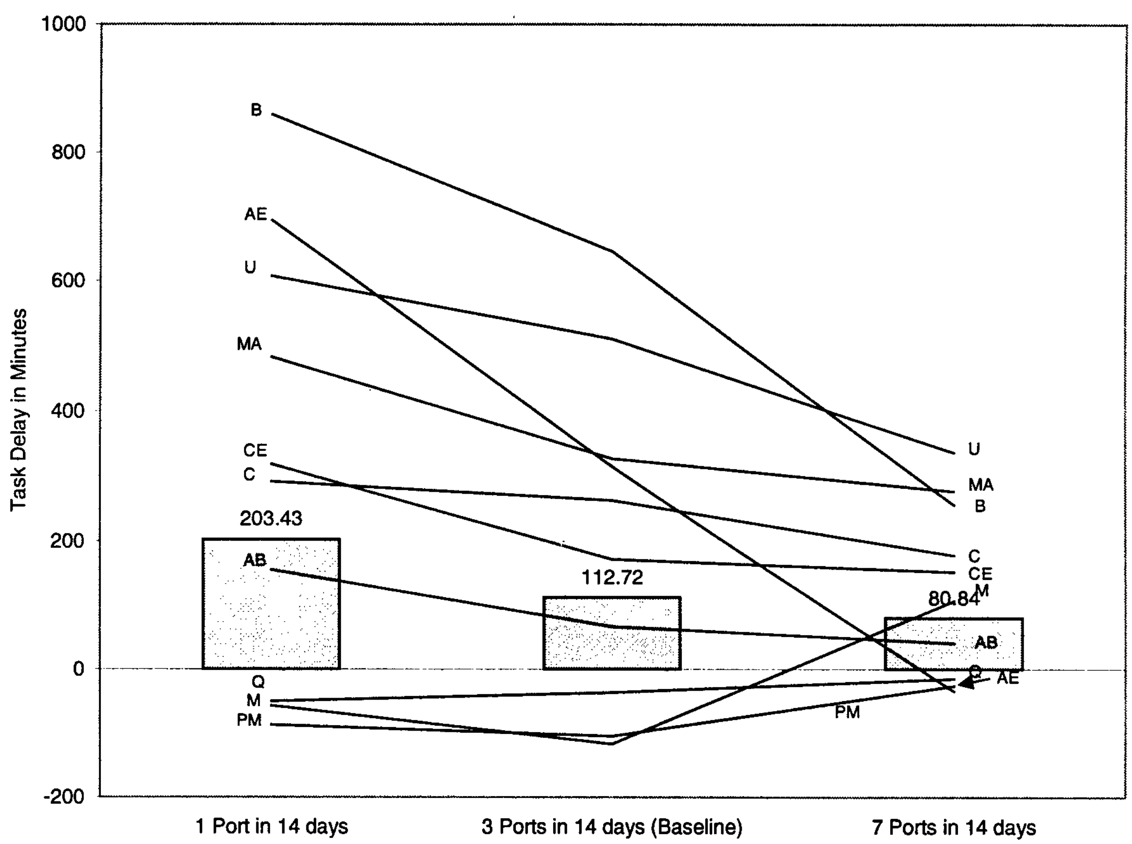


Figure 5. The Task Delay in Minutes for Three Port Call Frequencies.

2.5 Port Call Frequency: Conclusions

This analysis shows that the frequency of port calls affects task workload and the overall crew needs of a vessel. Port calls affect crew needs through additional navigation requirements, line handling, and cargo operations. These effects can be quantified by using CSEM to identify specific effects on particular crew types. The Master's workload is particularly sensitive to the number of hours in restricted waters. The Mates' and ABs' workload is more sensitive to the line handling and cargo operations, which depend on the number of port calls. As the frequency of port calls increases from 3 in 14 days to 7 in 14 days, there is a need for an additional Mate and AB. Similarly, when the frequency is reduced to 1 port call in 14 days, the reduced workload makes it feasible to operate without the assistance of a shore-based loading Mate. Overall, this analysis shows that operational factors associated with the voyage profile can influence crew complements.

3.0 Analysis of Shore-based Maintenance Options

3.1 Shore-based Maintenance: Background

Crews typically invest a substantial effort in ship maintenance. Allocating a portion of the maintenance requirements to shoreside support will reduce the workload and possibly crew size. Conversely, delegating maintenance tasks to shoreside support might not have an appreciable effect on overall workload when all the other shipboard tasks are considered. Therefore, shoreside maintenance support, in and of itself, might not allow reduced manning. As companies explore the costs and benefits of shore-based maintenance, it is likely that they will request crew reductions as shoreside maintenance is increased. CSEM can reveal whether shoreside maintenance significantly offsets crew work-hours and provide the Coast Guard with a better basis for reviewing industry requests for crew reductions.

3.2 Shore-based Maintenance: Test Scenarios

A survey of potential shore-based maintenance policies identified specific maintenance tasks that could comprise four levels of shore-based maintenance (see Appendix A for details). The four levels of maintenance were defined to represent a range of reasonable maintenance scenarios for future shoreside support. The "low" level of shoreside support represents current operations. The four levels represent a consensus of likely levels of support:

1. Very High: goes beyond current expectations and assumes that the shore-based crew performs all maintenance tasks except engine room cleaning.

2. High: shore-based crew performs all maintenance tasks except vessel and engine room fabric maintenance and engine room cleaning.

3. Medium: shore-based crew performs maintenance of navigation and communication equipment, air conditioning and ventilation systems, steering gear, generator, evaporator, pump and piping systems, and main engine.

4. Low: shore-based crew performs only partially supports maintenance of navigation and communication equipment and air conditioning and ventilation systems. Because these tasks are only partially supported by shore-based crews, they are marked "Partial" on Table 8.

Table 7. Four Levels of Shore-based Maintenance.

Type of Maintenance	Four Levels of Maintenance Activities Performed by Shore-based Crew			
	Very High	High	Medium	Low
5.1 Navigation equipment	X	X	X	Partial
5.2 Communication equipment	X	X	X	Partial
5.3 Vessel fabric (painting & chipping)	X			
5.4 Cargo, deck, and hull equipment	X	X	X	
5.5 Fire fighting equipment	X	X		
5.6 Lifesaving equipment	X	X		
5.7 Tools and test equipment	X	X		
5.8 Plumbing	X	X		
5.9 Galley	X	X		
5.10 Main engine	X	X	X	
5.11 Boiler	X	X		
5.12 Fuel oil system	X	X		
5.13 Evaporator system	X	X	X	
5.14 Generator	X	X	X	
5.15 Electrical system	X	X		
5.16 Pump	X	X	X	
5.17 Piping	X	X	X	
5.18 Steering gear	X	X	X	
5.19 Inert gas system	X	X		
5.20 Engine system fabric	X			
5.21 Heating, A/C, and ventilation	X	X	X	Partial
5.22 Sewage system	X	X		
5.23 Engine room cleaning				

Each level of shore-based maintenance shown in Table 7 comprises one test scenario. In addition, three more scenarios were defined when shore-based crews also performed repair work. In total, seven scenarios were analyzed: maintenance and repair support for very high, high, and medium levels of shore-based support and the baseline condition. Although the very high level of shore-based maintenance relieves the crew of almost all maintenance tasks, the crew has many other tasks associated with operational demands of the ship. Appendix C documents these tasks.

The test scenarios use the baseline port call frequency (3 ports in 14 days) and the baseline crew complement. The baseline crew complement consists of 24 people including:

- Master
- 3 Mates
- Day-working Boatswain
- 6 ABs
- Utility
- Chief Engineer
- 3 Assistant Engineers
- 3 Qualified Members of the Engineering Department
- 2 Pumpmen
- Chief Steward
- 2 Cooks

The other conditions of the test scenarios match the baseline condition described in the first analysis.

3.3 Shore-based Maintenance: Limits and Assumptions

Several important assumptions govern the interpretation of the shoreside maintenance analysis. Most importantly, the analyses assume that shoreside workers can perform maintenance as effectively and quickly as shipboard crew members. To the extent that crew members are more familiar with the ship's machinery or have a deeper commitment to quality workmanship, shoreside maintenance would be less effective than the ship's crew. Because shoreside maintenance is only available in port, and will likely be available at a limited number of ports, it may take longer to address maintenance and repair tasks. This could be a particularly important consideration for repair tasks, where it is impossible to coordinate port calls with the timing of mechanical failures. Because it is impossible to coordinate shoreside support in advance of an equipment failure, repair tasks may not be completed as quickly when they are delegated to shore-based workers. The final assumption is that the effectiveness of shoreside maintenance does not depend on engine type, ship age, level of automation, or vessel route. This may not be true in all cases, such as when the vessel route includes ports where shoreside support is unavailable. Similarly, certain equipment may require special expertise that shoreside personnel may not have.

To summarize, important assumptions regarding shoreside maintenance include:

- Shore-based maintenance is as effective as ship-based maintenance and does not require re-work by shipboard crew members.
- Shore-based crew are available to perform maintenance and repairs in a timely manner.
- Different types of engines, ship age, level of automation, and the route of a vessel have little influence on the effectiveness of shore-based maintenance.

3.4 Shore-based Maintenance: Findings

Table 8 shows how crew needs change with different levels of shore-based support. Moderate levels of support for maintenance and repair decrease the need for a Pumpman. (Note that the baseline scenario has three port calls in 14 days; if port call frequency were increased, the increased line handling and cargo duties may not allow these reductions.) High and very high levels of maintenance and repair support make it possible to switch the Boatswain from a dayworker to a watchstander, and remove one AB. Any crew reductions must consider watchstanding requirements and operational tasks assigned to each crew type. Appendix C contains a detailed description of all the tasks assigned to the crew types. Unless the watchstanding requirements are reduced, the number of QMEDs cannot be reduced.

Table 8. Change in Crew Needs with Different Levels of Shore-based Support.

Shoreside Support	Overall Crew	Change from Baseline Crew
Low (Baseline)	24	None
Medium (Maintenance), Medium (Maintenance & Repair)	23	Subtract one Pumpman
High (Maintenance), High (Maintenance & Repair), Very High (Maintenance), or Very High (Maintenance & Repair)	22	Subtract one AB and one Pumpman

A statistical analysis of variance (ANOVA*) was performed to look at the relationships between shore-based maintenance support, crew types, and the five measures of shipboard activity or crew overload:

- Work, the mean number of hours worked each day;
- WGTE18, the percentage of days with ≥ 18 hours of work;
- Busy, the mean time worked on non-watch tasks each day
- D_OPA90, the percentage of days in which one or more crew members worked more than the OPA '90 work-hour limit;
- Delay, the mean time tasks were delayed each day.

As the level of shore-based maintenance support increased, there was a modest decrease in crew work activity as shown by a small but significant effect on the variables Work, Busy, and D_OPA90. There was a significant interaction effect for each of these three variables, indicating that the influence of shore-based maintenance is not uniform across the crew. Specifically, the level of shore-based maintenance has the greatest effect on specific crew types, such as the Assistant Engineer, the Boatswain, and the Pumpman.

Figure 6 shows that the average amount of work decreases only slightly with increasing levels of shore-based maintenance. Because only some crew members conduct maintenance, the workload reduction is not uniform across the crew. The crew types most affected by shore-based maintenance are the Assistant Engineers, Qualified Members of the Engineering Department (QMEDs), Pumpmen, and the Boatswain. Interestingly, even high levels of shore-based support does not have a large effect on the ABs. This may be due to watchstanding requirements and the demands of operational tasks such as cargo equipment testing, cleaning, and cargo handling requirements. Even the highest level of shore-based support leaves the Pumpmen with nine hours of work each day, compared to just over ten hours for the baseline condition. This relatively small effect shows that operational demands may outweigh the maintenance demands.

* The ANOVA table is provided in Appendix D.

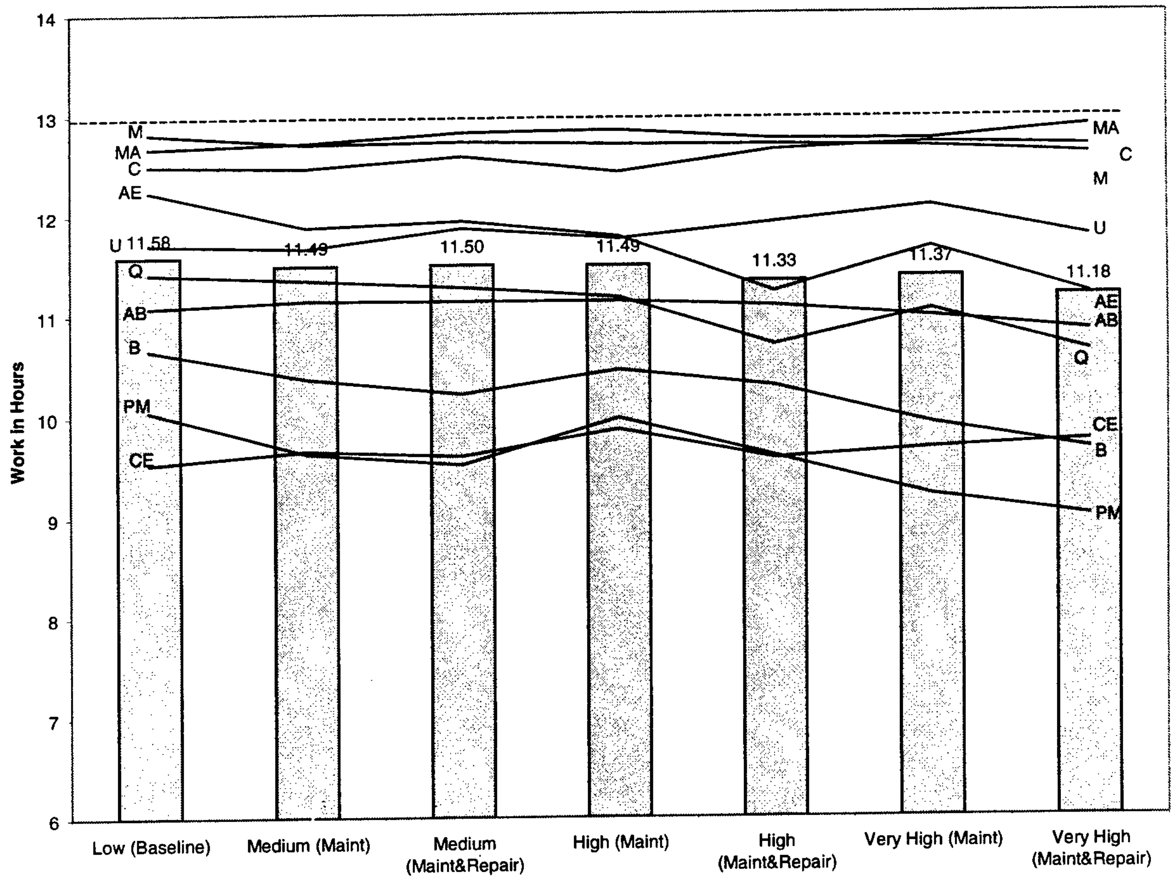


Figure 6. The Average Hours of Work Each Day for Seven Levels of Shore-based Maintenance.

Figure 7 shows that the maintenance support has a minimal effect on the number of extremely long workdays. This is consistent with the nature of much of the maintenance work. Few tasks are longer than eight hours and most long maintenance tasks can be interrupted and finished later. Furthermore, many maintenance tasks can be delayed and performed later if crew members are not immediately available to perform them. Even when the crew performs a lot of maintenance work, as in the baseline condition, crew members can fit the work into their workday without overload. This figure suggests the demands of port calls, which have a large effect on ABs, Mates, and the Master, are a more important determinant of long work days compared to the level of maintenance support.

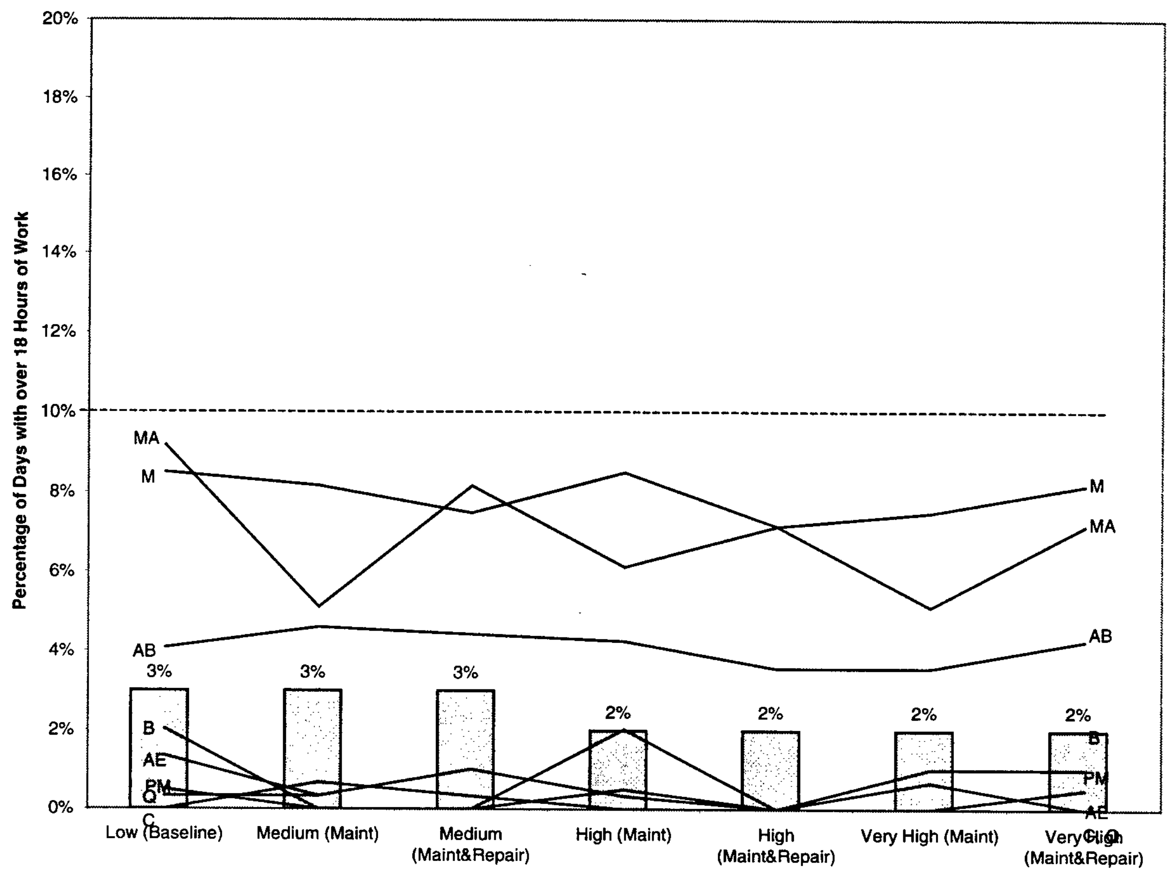


Figure 7. The Percentage of Days with More than 18 Hours for Seven Levels of Shore-based Maintenance.

Figure 8 confirms the effect of shore-based support. The amount of time busy on non-watchstanding tasks declines with increasing maintenance support. Because some maintenance can be done during watchstanding, the decline in the time busy with tasks does not lead to a large decrease in work hours. This is most evident for the QMEDs, who see a 43 percent drop in their time busy on non-watch tasks, but only a seven-percent drop in work hours. Interestingly, some crew members become busier with increasing shore-based support. Both the Master and Chief Engineer see slightly greater activity as the shore-based support frees crew members to pursue other operations that require their supervision. This increase might be even greater as the Master, Mate, and Chief Engineer might do extra work coordinating shore-based maintenance.

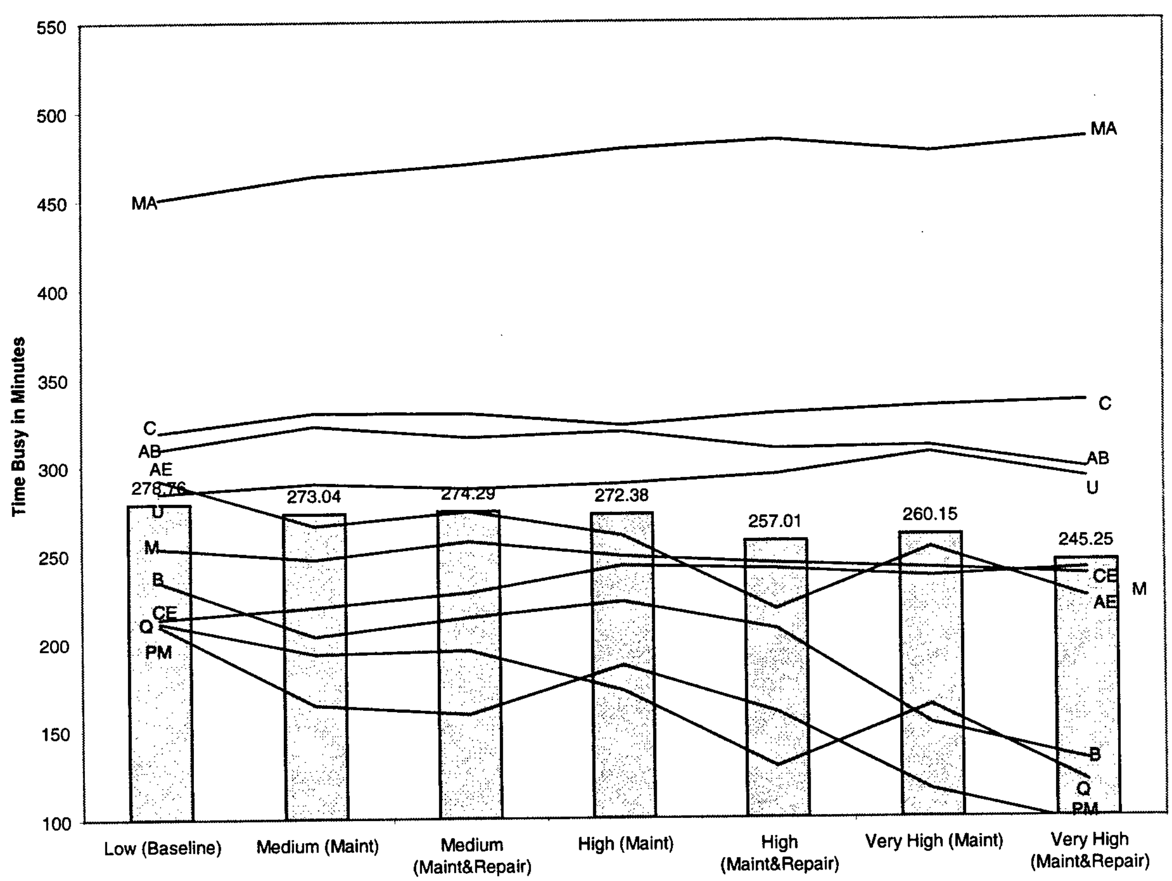


Figure 8. The Average Time Busy with Non-watchstanding Tasks for Seven Levels of Shore-based Maintenance.

A consistent pattern is seen when overages are considered. In addition, the strong interaction indicates that some crew types are more affected by the changes in maintenance policy than others. The Assistant Engineers see the largest decline in overages, with a 74 percent decrease. The QMEDs and the Boatswain also see moderate declines as more work is done by shore-based crews. A large part of these declines is associated with shore-based support of repair activities. When shore-based support only addresses routine maintenance, the declines are not nearly as large. Figure 9 shows that crew nonconformities decline most dramatically when the shore-based crew also performs repair work.

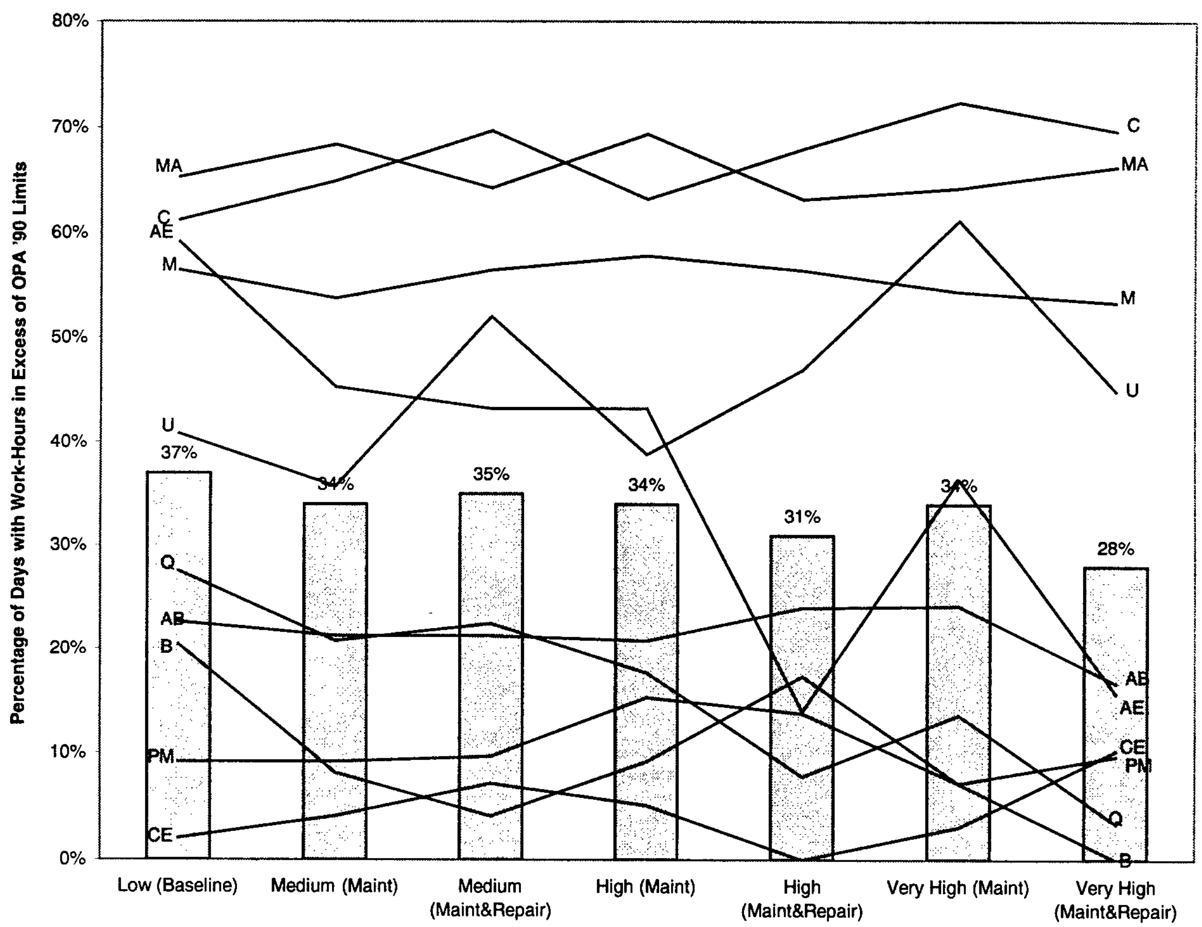


Figure 9. The Percentage of Days which Exceed OPA '90 for Seven Levels of Shore-based Maintenance.

Figure 10 shows that shore-based repair work does not have a large effect on task delays. This figure shows a slight decline in task delays for the Mates, Chief Engineer, Assistant Engineer, and Pumpmen when shore-based support performs repairs in addition to routine maintenance. However, these declines do not reach statistical significance.

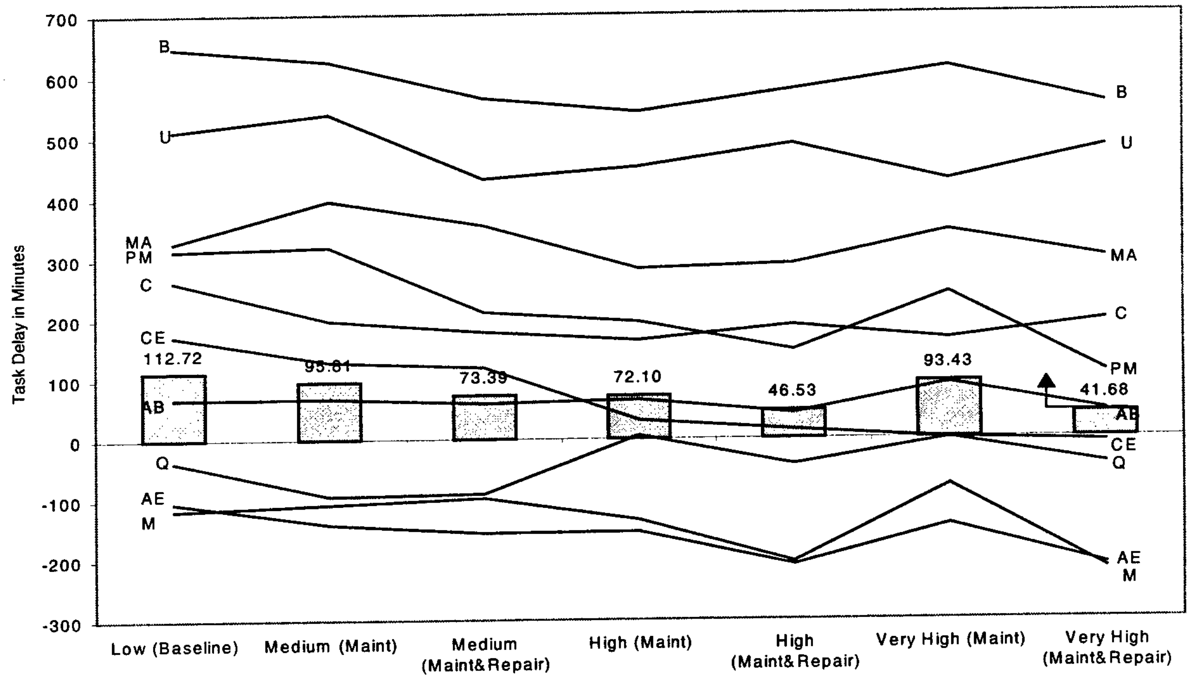


Figure 10. The Task Delay for Seven Levels of Shore-based Maintenance.

Table 9 shows the distribution of crew needs over the crew types for the baseline voyage, which has a low level of shore-side maintenance support. The crew needs show the number of person days of work required to complete each category of tasks, assuming twelve hours of work per day. This table shows the relatively low load associated with the maintenance activities. Much more effort is expended with the watchstanding and operation of equipment. Specifically, the function Engineering System Monitoring, Control, and Operation consumes nearly three times the effort of maintenance and repair activities. This distribution of effort shows that the crew needs of the engineering department are driven by activities other than maintenance tasks.

Table 9. The Distribution of Crew Needs over Crew Types and Shipboard Functions. (Entries are the number of person days (assuming a 12-hr workday) needed to perform each function.)

Fractional Crew Needs Based on Work-Hours of Tasks

1.0 Command & Control

MA	M	B	AB	CE	AE	Q	P	U	C
0.58	0.02			0.17					

2.0 Navigation

MA	M	B	AB	CE	AE	Q	P	U	C
0.03	1.65		3.14	0.02					

3.0 Communications

MA	M	B	AB	CE	AE	Q	P	U	C
0.02	0.02								

4.0 Engineering System Monitoring, Control, and Operations

MA	M	B	AB	CE	AE	Q	P	U	C
		0.02	0.02	0.36	2.9	2.0	0.02		

5.0 Scheduled Maintenance & Testing

MA	M	B	AB	CE	AE	Q	P	U	C
	0.04	0.16	0.18		0.25	0.29	0.29	0.14	

6.0 Unscheduled Maintenance & Repair

MA	M	B	AB	CE	AE	Q	P	U	C
	0.02	0.03	0.02	0.06	0.18	0.23	0.01	0.15	

7.0 Emergency Response

MA	M	B	AB	CE	1E	Q	P	U	C

8.0 Training & Drills

MA	M	B	AB	CE	AE	Q	P	U	C
0.02	0.09	0.02	0.02	0.04	0.08	0.02	0.02	0.02	0.04

9.0 Management & Administration

MA	M	B	AB	CE	AE	Q	P	U	C
0.12	0.13	0.18		0.04	0.02				

10.0 Internal Ship Communications & Meetings

MA	M	B	AB	CE	AE	Q	P	U	C
0.01									

11.0 Regulatory Compliance

MA	M	B	AB	CE	AE	Q	P	U	C
0.03	0.02	0.03	0.03			0.02	0.03		

12.0 Cargo Responsibilities & Passengers Care

MA	M	B	AB	CE	AE	Q	P	U	C
0.02	0.83	0.07	0.05		0.15	0.08	0.19		

13.0 Hotel Services

MA	M	B	AB	CE	AE	Q	P	U	C
								0.56	1.65

14.0 Arrival, Departure & Port Watchkeeping

MA	M	B	AB	CE	AE	Q	P	U	C
0.06	0.33	0.10	0.94		0.09				

3.5 Shore-based Maintenance: Conclusions

Increasing shore-based support reduces workload and suggests potential crew reductions. However, much of this reduction is offset by watchstanding duties. For example, the total hours worked, which include watchstanding responsibilities, decline relatively little compared to the declines in the time spent busy with non-watchstanding tasks. Any crew reductions, such as removing a QMED, need to consider how to satisfy the watchstanding requirements. Currently, the analysis assumes that the engineering watchstanding requires an Assistant Engineer and a QMED. Thus, the reduced maintenance and repair load would not justify reducing the number of QMEDs. Similarly, the workload of the pumpmen drops with increased shore-based maintenance and repair support; however, the several cargo handling activities require the two pumpmen. The analysis suggests the reduction in maintenance and repair work might justify a reduction of pumpmen; however, their specific cargo handling responsibilities would need to be examined carefully before implementing reductions. The results suggest that watchstanding and operational tasks govern workload and crew needs.

The results also show that supporting repair work in addition to maintenance can have a major effect on workload. Even very high levels of shore-based maintenance support do not have the same effect as moderate levels of shore-based maintenance and repair support. Unfortunately, shore-based repair work may not be feasible because it cannot be planned and it may be difficult to coordinate unplanned repairs with timely cargo transport. The difficulties of shore-based repair support, combined with the demands of watchstanding, make crew reductions based on shore-based maintenance difficult.

4.0 Analysis of OPA '90, STCW, and ILO Work/Rest Standards

4.1 Work/Rest Standards: Background

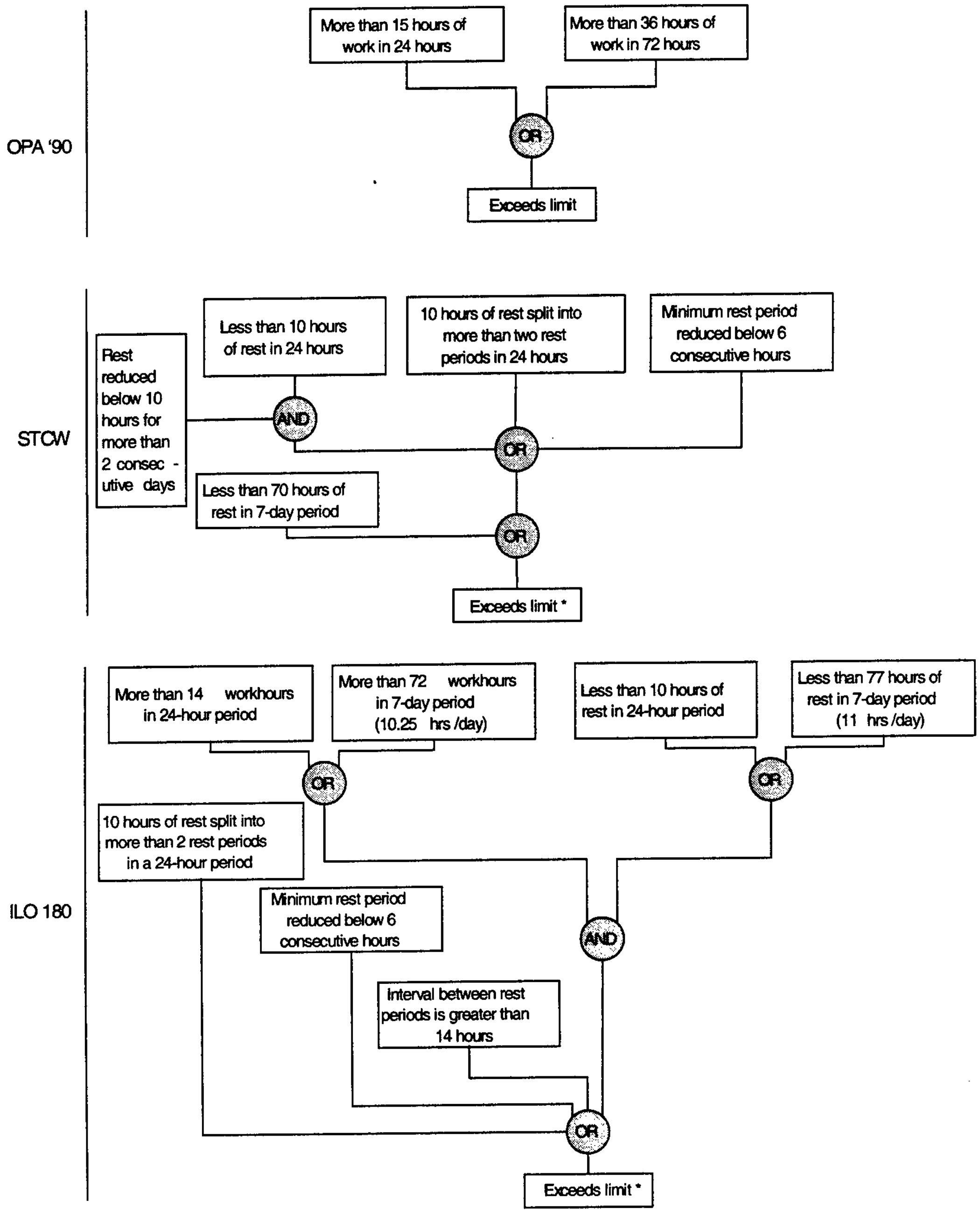
Standards that govern mariner work/rest schedules either limit the total hours worked, mandate minimum rest periods, or do both, combining work-hour limits and minimum rest periods. As the maritime community recognizes the importance of adequate rest, more stringent and complex work/rest standards are likely to be adopted. Since work/rest standards tend to limit the amount of work the crew is permitted to do, they could increase the crew needs of a vessel. CSEM can analyze the consequences of existing and proposed standards. Using CSEM's analysis capabilities, the Coast Guard can lead the international community in the development and refinement of various work/rest standards. For the present analysis, we considered three work/rest standards: OPA '90; the STCW Section A-VII/1; and ILO 180 Part II, Article 5.

OPA '90, STCW, and ILO 180 work/rest standards impose very different restrictions on shipboard operations. OPA '90 limits work hours and STCW mandates rest periods, whereas ILO 180 stipulates both maximum work hours and minimum rest periods. OPA '90 limits the total number of hours worked to 36 in a 72-hour period, and to 15 in a 24-hour period. STCW stipulates a minimum rest period of 10 hours in any 24-hour period. These 10 hours can be divided into no more than two periods, and one of the periods must be at least 6 hours in length. The rest period can be reduced to 6 consecutive hours for no more than two consecutive days, as long as 70 hours of rest are provided over a seven-day period.

ILO 180 limits work hours to a maximum of 14 in any 24-hour period, and 72 hours in any seven-day period. Alternatively, ILO 180 mandates minimum rest periods of at least 10 hours in any 24-hour period, and 77 hours in any seven-day period. Like STCW, ILO 180 stipulates that the hours of rest may be divided into no more than two periods, one of which must be at least 6 hours in length. However, ILO 180 also stipulates that the interval between consecutive rest periods must be no more than 14 hours. Although STCW applies only to watchstanding crew members, this analysis applies the STCW standard to all crew members in order to provide a meaningful comparison of the various work/rest standards. The variety of work/rest restrictions represented in these standards provide a useful test of CSEM's analytic power.

4.2 Work/Rest Standards: Test Scenarios

Figure 11 depicts the work-hour limits and minimum rest periods associated with three major work/rest standards. This figure shows the conditions that lead to overages for each standard. Of the three standards, ILO 180 is the most complicated and has the greatest number of constraints on how crew members can work. The great number of constraints could lead to differences in hours worked, number of overages, and task delays. Each work/rest standard was examined using the baseline scenario of three port calls in 14 days.



* Note that STCW may permit the work-hour limit to be exceeded in cases where there are "overriding operational conditions;" ILO 180 may permit longer work hours where alternate arrangements are put in place through collective bargaining.

Figure 11. Differences between Three Work/Rest Standards.

4.3 Work/Rest Standards: Limits and Assumptions

Several assumptions merit consideration when considering the results of the work/rest standards analysis. First, the importance of each standard was assumed to be the same and that exceeding each standard had the same effect on the behavior of the crew members. If some standards have a regulatory standing and others have an advisory standing, then crew members may attend to one and not the other. Second, we assumed that compliance with all three standards was guided by the logic described by Lee et al (1997), where crew members work on high-priority tasks even if they do not conform to work/rest standards. In contrast, they will delay medium and low-priority tasks in order to stay within the standards. This logic may not reflect subtle strategies crew members use to arrange work so that they conform to the limits. To the extent that these strategies are not included in CSEM, CSEM may overestimate the number of nonconformities. The final assumption is that type of voyage and the level of workload will not substantially change the nature of the results.

To summarize, assumptions that should guide the interpretation of work/rest standards include:

- Compliance with each standard is equally important.
- Compliance with standards and task performance is guided by the logic defined in Lee, et al (1997), where crew members work on high-priority tasks even if it involves exceeding a work/rest standard, but low-priority tasks are delayed rather than incurring an overage.
- The pattern of results does not depend on workload of the test scenarios.

Appendix B contains a detailed description of the changes made to CSEM to accommodate the analysis of work/rest standards.

4.4 Work/Rest Standards: Findings

A statistical analysis of variance (ANOVA*) was performed to look at the relationships between the different work/rest standards and the five measures of shipboard activity or crew overload:

- Work, the mean number of hours worked each day;
- WGTE18, the percentage of days with ≥ 18 hours of work;
- Busy, the mean time worked on non-watch tasks each day
- Nonconformance - in this analysis, work/rest practices which do not conform with whichever work/rest standards are being tested;
- Delay, the mean time tasks were delayed each day.

The different work/rest standards have a significant and large effect on the variables Work, Busy and Nonconformance. A moderate interaction effect was found, indicating that work/rest standards do not affect all crew types in a uniform way. The Master and the ABs were most affected by the different work/rest standards examined.

Figure 12 shows that the various work/rest standards produce essentially equivalent numbers of hours worked. The average for different work/rest standards differs by only about half an hour.

* The ANOVA table is provided in Appendix D.

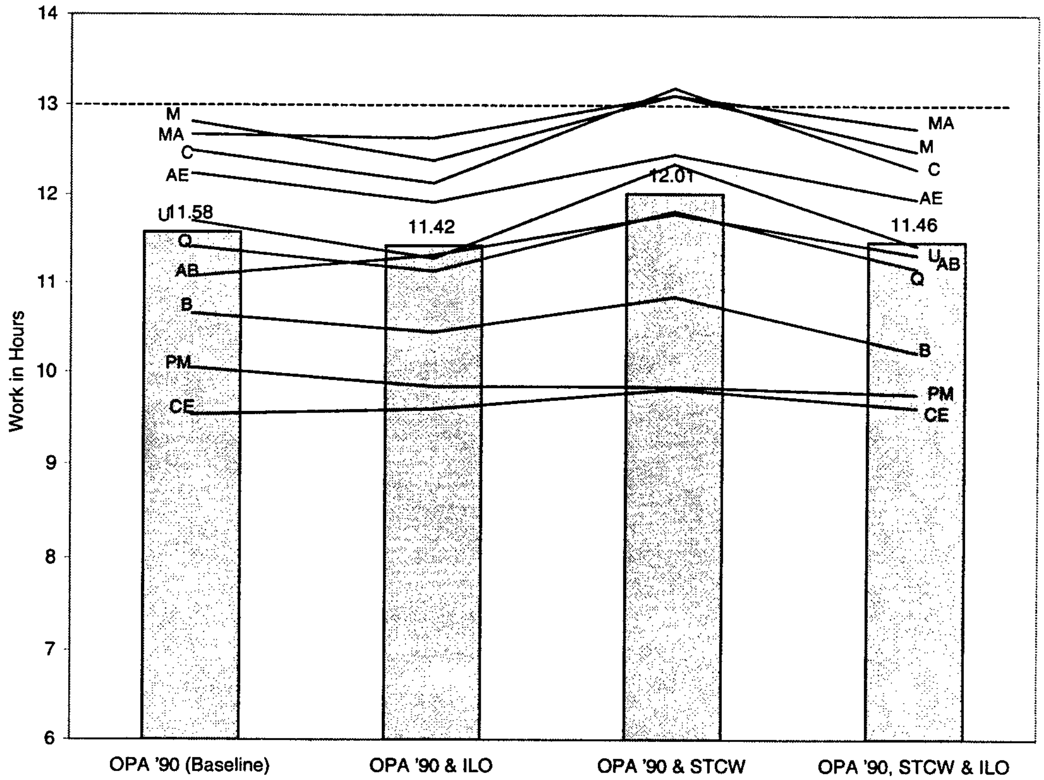


Figure 12. The Average Hours of Work for Each Work/Rest Standard.

Figure 13 shows a similar pattern, with no strong, consistent differences between the various work/rest standards. As a point of comparison, in the port call frequency analysis, the percentage of days with more than 18 hours of work more than doubled from one port call in 14 days to seven port calls in 14 days. The effect of work/rest standards is much smaller and does not approach statistical significance. The apparent increase in hours worked for the "OPA '90 and STCW" condition is unexpected and merits further analysis to determine the nature of the anomaly.

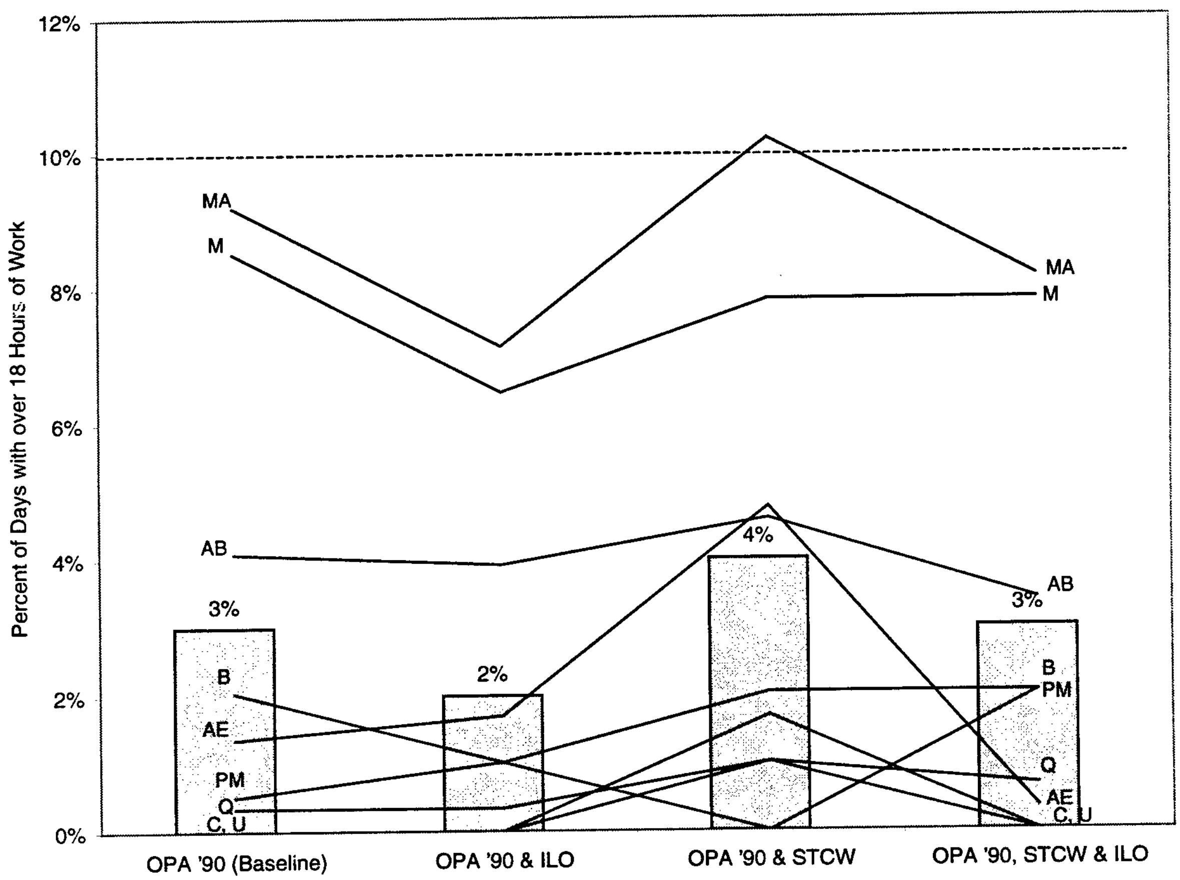


Figure 13. The Percentage of Days with More than 18 Hours of Work for Each Work/Rest Standard.

Figure 14 shows that the time spent busy on non-watchstanding tasks is sensitive to differences between work/rest standards. Specifically, the Master and ABs are affected most by the differences, but the other crew types follow the same pattern. Crew members are most fully occupied on tasks in the baseline condition. Because the other conditions include work/rest restrictions in addition to OPA '90, one would expect a lower level of activity. The graph reflects this with a lower level of activity for each of the other conditions. The conditions that include ILO 180 are the most dramatically affected. The condition which includes all three work/rest standards is little different than that of OPA '90 and ILO 180. This is because ILO 180 restricts crew activity considerably more than OPA '90 or STCW.

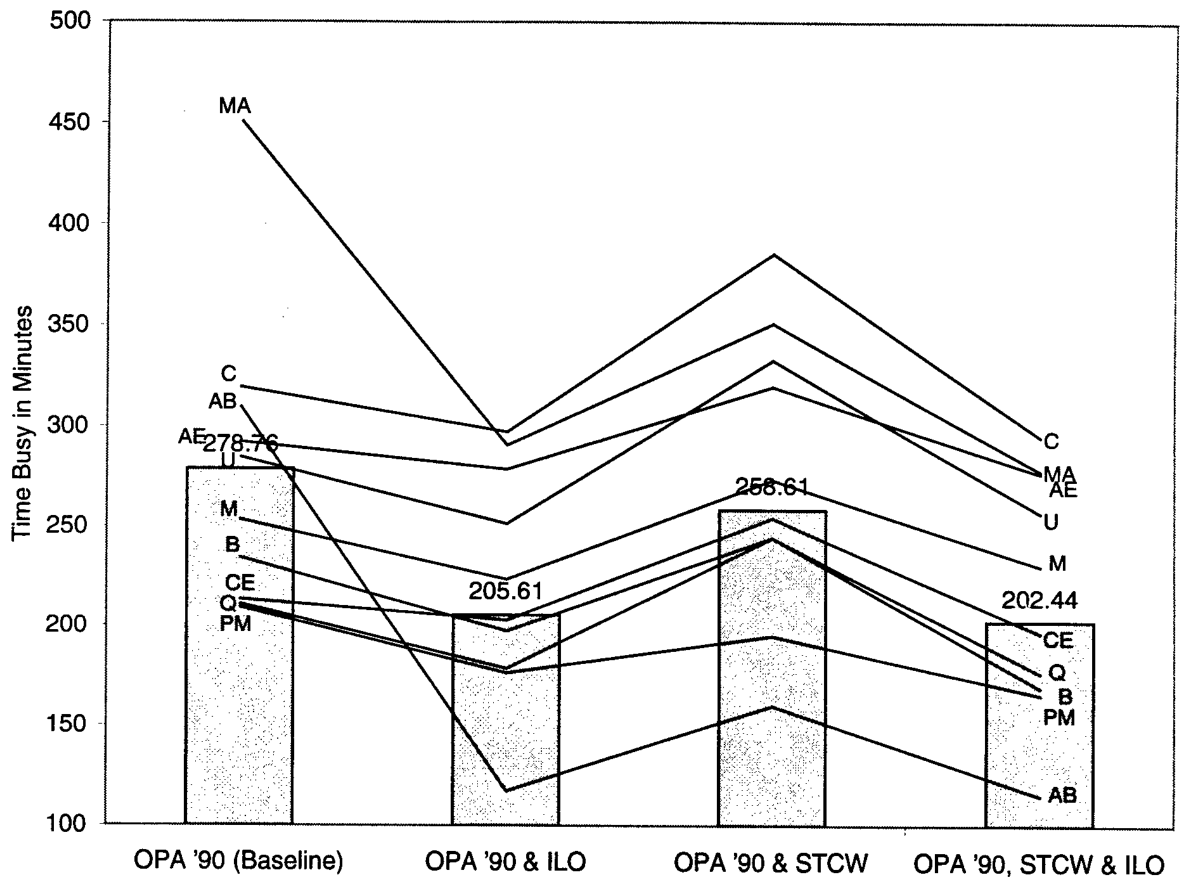


Figure 14. The Average Time Busy with Non-watchstanding Tasks for Each Work/Rest Standard.

The pattern seen for time busy on non-watchstanding tasks is repeated for the percent of days with work/rest nonconformities shown in Figure 15. The least restrictive work/rest standard (OPA '90) produces the fewest overages, and the most restrictive (OPA '90, STCW, and ILO 180) produces the most. Again, ILO 180 combined with OPA '90 is a more restrictive standard, compared to OPA '90 alone. Including STCW with ILO 180 does not change the number of nonconformities.

Figure 15 shows a generally high prevalence of crew whose work/rest hours do not conform to the various standards. Two factors contribute to this phenomenon. First, overages can occur with relatively small differences in the work/rest standards. For example, working 13 hours for one day and 12 hours the next two days would cause a person to exceed OPA '90 for three days. Second, there are many high-priority tasks and they are assigned to crew members even if they result in overages. Performing high-priority tasks even if they result in work/rest nonconformities is consistent with actual shipboard activities, but actual crew members may arrange their work to minimize nonconformities in a way that is not reflected in CSEM. A careful analysis of actual shipboard activity could show whether the high level of overages predicted by the model accurately reflect reality.

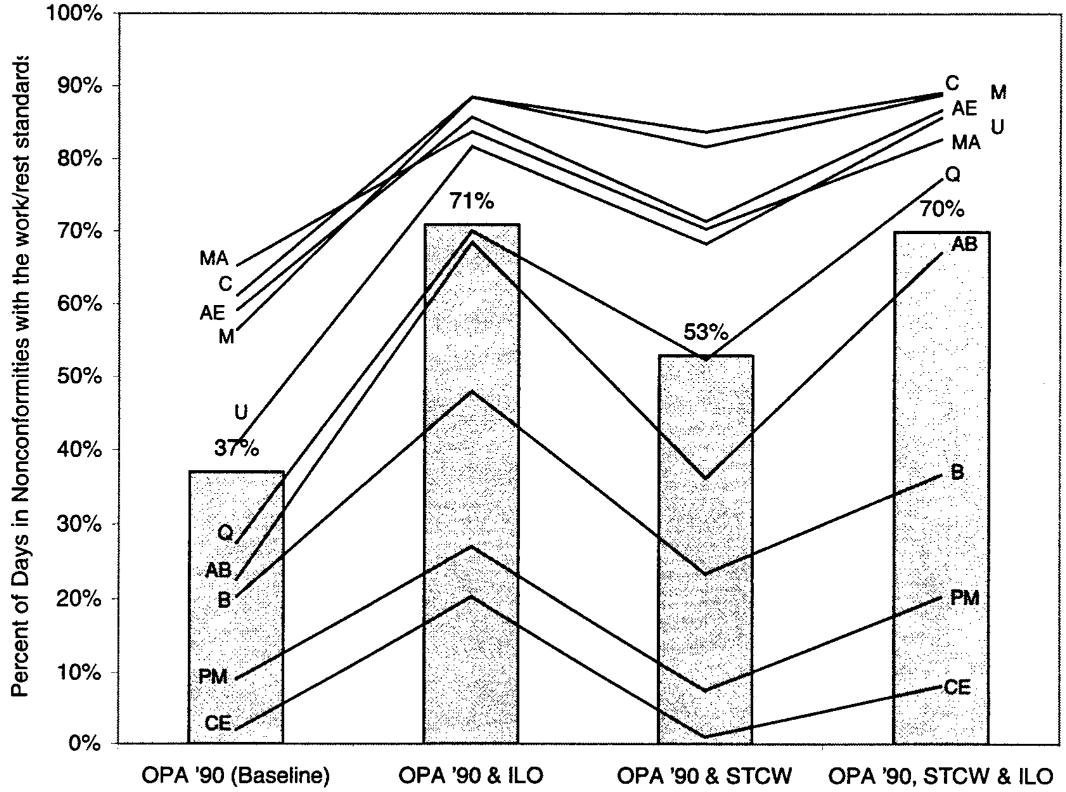


Figure 15. The Percentage of Days in which Work/Rest Practices were in Nonconformance with Each Work/Rest Standard.

As shown in Figure 16, the number of minutes tasks were delayed does not follow the expected pattern; longer delays do not correspond with more restrictive combinations of work/rest standards. The effect of the standards is not statistically significant for the average task delay across the scenarios, and there is no consistent effect for the crew types.

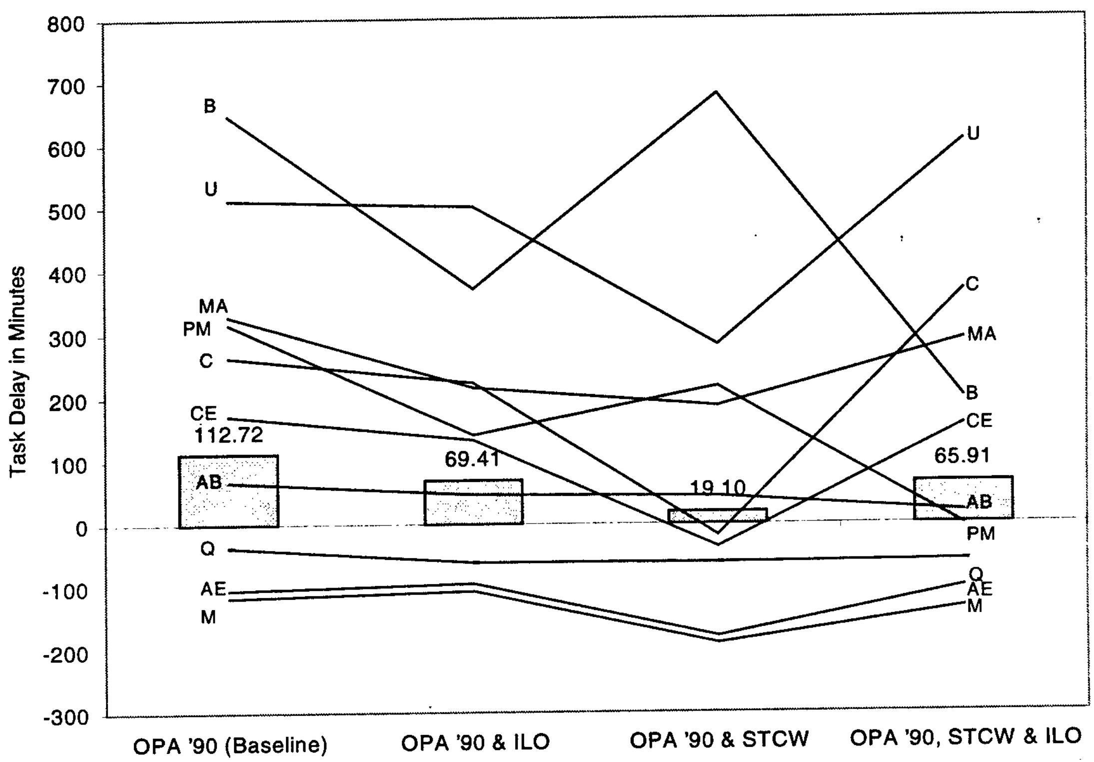


Figure 16. The Average Task Delay for Each Work/Rest Standard.

4.5 Work/Rest Standards: Conclusions

Analysis of three work/rest standards shows that imposing additional standards beyond OPA '90 has a modest affect on shipboard activity. In particular, the number of nonconformities increases and the time busy on non-watchstanding tasks decreases; however, the standards do not substantially change the number of long work days, task delays, or the number of hours worked.

This may reflect the relatively large number of high-priority tasks that cannot be delayed. This suggests that high priority tasks and watchstanding duties, which are performed even when people exceed the work/rest standards, govern extreme work days independently of the work/rest standard. In contrast, the effect of the work/rest standard on time busy with non-watchstanding tasks is quite large. The most restrictive combination (OPA '90, STCW, & ILO 180) reduces the average time to 202 minutes per day, compared to 278 minutes per day when only OPA '90 is applied. This is a larger effect than the variation seen in the port call frequency scenario, where one port call in 14 days produces 227 minutes per day and seven port calls in 14 days produces 283 minutes per day. The statistical measure of effect size confirms the large effect of the restrictive work/rest standards; η^2 is 0.88 for the effect of the work/rest standards and 0.74 for the frequency of port calls. Overall, different work/rest standards have a moderate effect on shipboard activities and crew member work/rest patterns.

CSEM and the analyses make several assumptions that may not match actual shipboard operations. The analysis assumes that crew members would interpret the standards exactly as they are written. However, the standards, ILO 180 in particular, are quite complex and crew members are not likely to interpret them exactly as they are written. Instead, they are likely to develop heuristics that are consistent with the standards, but are much simpler. For example, many mariners view OPA '90 as a 12-hour work day restriction (a simplification of the limit of 36 work hours in a 72-hour period), ignoring the complexity of the additional limit of 15 hours in a 24-hour period. With a complex standard like ILO 180, it is reasonable to assume mariners will adopt similar strategies to simplify the standard so they are able to manage their lives more easily. For example, one heuristic might be setting aside an 8-hour rest period each day and not working more than 12 hours a day. Alternatively, the complexity may lead mariners to disregard certain clauses, leading to occasional overages.

5.0 Implications

The analyses of port call frequency, shore-based maintenance, and work/rest standards make some important contributions to our understanding of how computer-based models can support crew size evaluation. These analyses highlight the need to identify appropriate measures and criteria to determine crew adequacy. These decisions are a joint determination of policy makers and modeling experts. We proposed two measures and identified tentative criteria for adding crew members. One measure reflects chronic overload (average hours worked) and the other identifies acute or transient overload (percent of days with more than 18 hours of work). We identified 13 hours per day and 10 percent of days with more than 18 hours of work as the criteria for adding crew members. This report examines other measures, with the time spent busy on non-watch tasks being a potential candidate for additional consideration. These measures provide a useful complement to nonconformities of work/rest standards, such as OPA '90. For example, average hours worked shows that even though the analyses show many overages, crew members do not work many hours beyond the limits.

A potential alternative to identifying absolute thresholds to judge crew size is to make relative judgements. This avoids the need for an absolute metric of crew adequacy and provides useful information for many analyses. The analyses in this report illustrate this technique by providing comparisons to a baseline. Comparing scenarios to a known baseline allows regulatory decisions to encompass a range of considerations that might be difficult to formulate explicitly. A comparison of port call frequency and shore-based maintenance support illustrates this point. Changing the frequency of port calls had a large effect[3] on crew work hours; this effect was not matched by extreme levels of shore-based maintenance and repair support. This comparison supports an important judgment of the relative impact of the operational factors. Absolute thresholds are not needed to show the importance of increasing the number of port calls.

Beyond port calls, another critical finding emerged for evaluating crew complements: watchstanding activities have a major influence on crew size. Most significant crew reductions

[3] This difference in size can be seen on the difference in work-hours or by comparing η^2, a statistical measure of effect size that is appropriate for repeated measures analysis of variance.

will depend on how watchstanding requirements are determined. If engine room watchstanding requirements can be met with an on-call engineer, then the number of QMEDs and Assistant Engineers will drop more than if a large shore-based maintenance program is enacted. Similarly, the need for ABs depends on the watchstanding requirements in open waters and restricted waters. Watchstanding requirements are an important determinant of crew size and are likely to govern most crew reductions in the future. CSEM provides a flexible framework for examining whether a crew can accommodate shipboard tasks after watchstanding requirements are changed and crew members are removed.

Changing watchstanding requirements are one example of how shipboard operations may change and affect the predictions of CSEM. More generally, changing the equipment, procedures, and shore-based support can affect the crew needed to perform tasks, which can affect the number and type of crew needed to safely operate the ship. The analyses in this report were based upon the tasks described in Appendix C. When these tasks change, crew needs may also change. As an example, since the time when the data in Appendix C were collected, changes have been made to the way food is prepared and served on some ships. Specifically, the introduction of self-service has changed the tasks of the steward's department, and has contributed to a reduction of the number of crew members in that department. This example illustrates how the task data used in a CSEM analysis must be evaluated to ensure that they accurately reflect current operating conditions. The predictions of CSEM are only as accurate and appropriate as the underlying data.

6.0 References

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Appendix A: Survey of Shipping Company Operations

A.1 Typical Voyage Profile

We developed a survey to collect data from shipping companies about typical voyage profiles of U.S. tankers, and about maintenance activities that are typically performed by shore-based personnel. We surveyed one representative at three different shipping companies.

The survey used to collect voyage information is on pages A-3 and A-4. Respondents described a representative sequence of ports that a ship might visit in a one-month period. They also estimated the duration of each ship's typical restricted waters transit, at-sea transit, and port call. Respondents described cargo-related demands on the ship's crew, and any unusual ship characteristics that might affect crew workload.

The results of the survey, summarized in Table A1, include data on 18 U.S. flag tankers. Table A1 groups the ships by average voyage leg duration, and includes:

(1) The number of ships in each group;
(2) The average voyage leg duration for each group of ships;
(3) The average port call duration for each group;
(4) The routes of the ships in each group;
(5) The type of cargo transported by the ships in each group;
(6) The number of crew aboard the vessels in each group; and
(7) Comments pertinent to each group.

The data in Table A1 guided our selection of the three port call frequencies (one port call in 14 days, three in 14 days, and seven in 14 days) examined in Section 2 of this report.

A-2 Ship Maintenance

The survey used to collect data on ship maintenance activities is on page A-6. Respondents told us which of 23 tasks are performed shoreside and which are performed onboard ship. Respondents also told us which tasks were performed by a different group of personnel five years ago and which tasks might be performed by a different group of personnel five years from now. The responses from the companies guided our definitions of low, medium, high, and very high shore-based maintenance as described in Section 3 of this report.

SHIPPING COMPANY SURVEY

Date ____________ Name ____

Company __________________________ Position ____________________________

Descriptions of Typical Voyages

We are conducting a survey regarding the typical voyages of the ships in your fleet, and we would like to ask you a few questions. Please fill in the attached tables with responses to these questions for each ship in your company's fleet.

1. What is a representative sequence of ports that each ship might visit in a one-month period?
2. What kind of cargo does each ship carry on each voyage leg (e.g., from Valdez to Cherry Point or from Long Beach to Portland, etc.)?
3. How many days (hours) is the voyage from Port A to Port B?
4. How many days (hours) is each visit to Port B?
5. Does the type of cargo impose special demands on the crew (e.g., frequent tank cleaning for refined products)?
6. Does the ship have any unusual characteristics that affect demands on the crew (e.g., gas turbine tanker with unattended engine room)?

If a typical voyage profile is not readily available for one or more ships, please forward information (if available) from which the above data can be extracted. Information to be forwarded for the following ships:

____

____

Typical Voyage Profile

Company: ______________ Ship: ________________ Total Crew Size: _____

Size of Steward Department: _____ Crew Size on Certificate of Inspection: _____

Voyage Leg		Cargo	Duration of Voyage Leg	Duration of Visit to Port B
Port A	Port B			
Example: Cherry Point	Valdez	none	4.5 days	20 hours loading
Valdez	Cherry Point	crude	4 days	22 hours unloading

Cargo Demands: ____

____

Ship Characteristics: ____

____

Table A1. Grouped ship summary data.

No. of Ships in Group	Average Voyage Leg Duration (days)	Average Port Call Duration (days)	Route	Cargo	Crew Size	Comments
1	0.50	0.50 – 1.0	Anacortes, WA to Portland, OR	Refined products	25	Once per month, otherwise route is variable on U.S. West Coast
1	0.75	1.0	Estero Bay, CA to El Segundo, CA	Crude oil	19	Extra 3rd mate
4	2.5 – 4.0	1.0	Pascagoula, MS to Ft. Lauderdale, FL, Richmond, CA to Portland, OR, and Richmond, CA to Rosarita Beach & La Paz, Mexico	Refined products	18	
4	3.5 – 4.0	1.0	Valdez, AK to Cherry Point or Anacortes, WA	Crude oil	21-23	
1	6.5	1.0 – 2.0	Valdez, AK to Honolulu, HI	Crude oil	21	Once per month, otherwise route is Valdez, AK to Anacortes, WA
4	7.0	1.0 – 1.25	Valdez, AK to Long Beach, CA	Crude oil	22	
4	11.0 – 17.0	1.0 – 3.0	Houston, TX through Panama Canal to Long Beach, El Segundo or Richmond, CA	Refined products	18–25	Route variable due to spot market trade

Shore-Based Maintenance

We are also interested in learning more about the ship maintenance that your company does shoreside:

Maintenance Task	Currently done shoreside?		Could be done shoreside, but is not at this time?
	Scheduled	Unscheduled	
5.1 Navigation equipment			
5.2 Communication equipment			
5.3 Vessel fabric (painting & chipping)			
5.4 Cargo, deck, and hull equipment			
5.5 Firefighting equipment			
5.6 Lifesaving equipment			
5.7 Tools and test equipment			
5.8 Plumbing			
5.9 Galley			
5.10 Main engine			
5.11 Boiler			
5.12 Fuel oil system			
5.13 Evaporator system			
5.14 Generator			
5.15 Electrical system			
5.16 Pump			
5.17 Piping			
5.18 Steering gear			
5.19 Inert gas system			
5.20 Engine system fabric			
5.21 Heating, A/C, and ventilation			
5.22 Sewage system			
5.23 Engine room cleaning			

Which of the above maintenance tasks, if any, are performed by a different group of personnel than five years ago? (e.g., Task X was done shoreside, but now it is done aboard ship.)

Which of the above maintenance tasks, if any, will be performed by a different group of personnel in the next five years?

Appendix B: Variables and Expressions Used to Calculate Compliance with Work/Rest Standards

CSEM was originally designed to accommodate a variety of work-hour limits. It was not originally designed to address rest requirements. Because the ILO 180 and STCW work/rest standards address rest requirements CSEM required substantial modification. This appendix documents the new variables and algorithms needed to examine the ILO and STCW standards.

Variables added to CSEM

C_WHis (35, 168) Work history for previous 168 hours (7 days) 1 working 0 resting

C_RHis (35, 168) Rest history for previous 168 hours (7 days) 1 resting 0 working

C_WCum (35, 3) Cumulative work hours over 1) 24 hour, 2) 72 hour, and 3) 168 hour periods

C_RCum (35, 4) Cumulative rest over 1) 24, 2) 48, 3) 72, and 4) 168 hour periods

C_RMax (35,2) Maximum duration of continuous rest period in previous 24 hours (1) and start time of the longest rest period in the last 24 hours

C_RStart (35) Start time of most recent rest period

C_REnd (35, 4) End time of the last 4 rest periods, with 1 being the most recent

C_CLT10 (35) Consecutive days with less than 10 hours of rest

C_Cond (35,19) Conditions specified by the work/rest standards

Conditional tests used to operationalize the work/rest standards

1) C_WCum (cr, 2)<36 *Work-hours <36 in 72 hour period* (OPA '90)

2) C_WCum (cr, 1)<15 *Work-hours <15 in 24 hour period* (OPA '90)

3) C_Cond(cr, 1)==1&C_Cond(cr, 2)==1 *Conditions 1 and 2 are true* (OPA90)

4) C_WCum (cr,1)<=14 *Maximum hours of work shall not exceed 14 hours in a 24 hour period*(ILO)

5) C_WCum (cr,3)<=72 *Maximum hours of work shall not exceed 72 hours in a seven-day period* (ILO)

6) C_RCum (cr, 1)>=10 *Rest hours shall not be less than ten hours in a 24 hour period* (ILO)

6) C_RCum (cr, 4)>=77 *Rest hours shall not be less than ten hours in a 24 hour period* (ILO)

7) V_Hour-C_REnd (cr, 3)<=24 *No more than two rest periods in 24 hour period* (ILO)

8) C_RMax (35)>=6 *One rest period in 24 hours must be at least six hours in length* (ILO)

9) V_Hour-C_REnd (cr, 1)<=14 hours or C_RHis(cr, Now)==1. *The interval between consecutive rest periods shall not exceed 14 hours* (ILO)

10) ((4 and 5 are true) or (6 and 7 are true)) and (7 and 8 and 9 are true) (ILO)

11) C_RCum (cr, 1)>=10 *Persons forming a watch shall be provided a minimum of 10 hours of rest in any 24-hour period*

12) V_Hour-C_REnd (cr, 3)<=24 *No more than two rest periods in 24 hour period* (STCW)

13) C_RMax (35)>=6 *One rest period in 24 hours must be at least six hours in length* (STCW)

14) C_CLT10 (cr) >2 *The minimum rest period of 10 hours may be reduced to not less than 6 consecutive hours provided that any such reduction shall not extend beyond two days* (STCW)

15) C_RCum (cr, 4) >= 70 hours *Not less than 70 hours of rest shall be provided in a 7 day period* (STCW)

16) (11 and 12 and 13 are true) or (13 and 14 and 15 are true) (STCW)

17) 3 and 10 are true (OPA '90 & ILO)

18) 3 and 16 are true (OPA '90 & STCW)

19) 3 and 10 and 16 are true (OPA '90, ILO, and STCW)

Intermediate calculations for variables

C_WHis (35, 168) @ hour

If C_Busy[cr]>0 or C_Sched[cr]=1 then C_RHis(cr,*):=0 else C_RHis(cr,*):=1

C_RHis (35, 168) @ hour

If C_Busy[cr]>0 or C_Sched[cr]=1 then C_WHis(cr,*):=1 else C_WHis(cr,*):=0

C_WCum (35, 3) @ hour

C_WCum(cr,1)=C_WCum(cr,1)+C_WHis(cr,*)-C_WHis(cr,*-24)

C_WCum(cr,2)=C_WCum(cr,2)+C_WHis(cr,*)-C_WHis(cr,*-72)

C_WCum(cr,3)=C_WCum(cr,3)+C_WHis(cr,*)-C_WHis(cr,*-168)

C_RCum (35, 4) @ hour

C_RCum(cr,1)=C_RCum(cr,1)+C_RHis(cr,*)-C_RHis(cr,*-24)

C_RCum(cr,2)=C_RCum(cr,2)+C_RHis(cr,*)-C_RHis(cr,*-48)

C_RCum(cr,3)=C_RCum(cr,3)+C_RHis(cr,*)-C_RHis(cr,*-72)

C_RCum(cr,4)=C_RCum(cr,4)+C_RHis(cr,*)-C_RHis(cr,*-168)

C_RMax(35,2) @ 24 hour

If (C_RStart(cr)>C_REnd[cr,1]) & (C_RMax(cr)<Now -C_RStart(cr)) then C_RMax(cr,1):=Now - C_RStart(cr)

C_RMax(cr, 2):=Now

If (C_RStart(cr)<=C_REnd[cr,1]) & (C_RMax(cr)<C_REnd[cr,1]-C_RStart(cr)) then
C_RMax(cr,1):=C_REnd[cr,1]-C_RStart(cr)
C_RMax(cr, 2):=Now

If Now-C_RMax(cr,2)>24 & (C_RStart(cr)>C_REnd[cr,1]) then
C_RMax(cr,1):=Now -C_RStart(cr)

If Now-C_RMax(cr,2)>24 &(C_RStart(cr)<=C_REnd[cr,1]) then
C_RMax(cr,1):=C_REnd[cr,1]-C_RStart(cr)

C_RLT10 (35) @ 24 hour
if C_RCum(cr,1) <10 then C_RLT10 (cr) = C_RLT10 (cr) +1 else C_RLT10 (cr):=0

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Appendix C: Detailed Task Assignments

This appendix contains the detailed data that describe each task in the baseline scenario. This task list provides the basis for all the analyses, defining the tasks performed by each crew type. These task data came from detailed analysis of shipboard tasks performed on three tankships (Lee, McCallum, Maloney, and Jamieson, 1997). Each crew member was interviewed at length about the tasks he performed in port, in restricted waters, and in open waters. Data were collected on the numbers and types of crew typically assigned to each task and the duration and frequency of task performance.

USCG CrewSEM – [Task-Crew Needs]

#	Task Name	Phase	Phase Type Description	Avg	Times	Per	Hrs/day Across Vayage	Req	Pool #1	Req	Pool #2	Req	Pool #3	Req	Pool #4
1	Command & Control			1.5				0		0		0		0	
1.1	Command, control & coordina	Port	1:Load	1.5	1	Day	0.43	1	M	1	CE				
1.1	Command, control & coordina	Port	2:Unload	1.5	1	Day	0.21	1	M	1	CE				
1.1	Command, control & coordina	RW	1:Inbound/Outb	1.5	1	Day	0.50	1	M	1	CE				
1.1	Command, control & coordina	OW	1:Normal	1.5	1	Day	1.86	1	M	1	CE				
1.2	Bridge resource management	RW	1:Inbound/Outb	1	1	Hour	4.00	1	M						
1.2	Bridge resource management	OW	1:Normal	1	2	Day	1.24	1	M						
1.3	Crew performance manageme	Port	1:Load	0.5	1	Day	0.14	1	M CM	1	CE				
1.3	Crew performance manageme	Port	2:Unload	0.5	1	Day	0.07	1	M CM	1	CE				
1.3	Crew performance manageme	RW	1:inbound/Outb	0.5	1	Day	0.17	1	M CM	1	CE				
1.3	Crew performance manageme	OW	1:Normal	0.5	1	Day	0.62	1	M CM	1	CE				
2	Navigation							0		0		0		0	
2.1	Bridge watchkeeping	RW	1:Inbound/Outb	1	1	Hour	4.00	1	CM 2M 3M						
2.1	Bridge watchkeeping	OW	1:Normal	1	1	Hour	14.86	1	CM 2M 3M						
2.2	Lookout	RW	1:Inbound/Outb	1	1	Hour	4.00	1	AB						
2.2	Lookout	OW	1:Normal	1	1	Hour	14.86	1	AB						
2.3	Steering	RW	1:Inbound/Outb	1	1	Hour	4.00	1	AB						
2.3	Steering	OW	1:Normal	1	1	Hour	14.86	1	AB						
2.4	Voyage passage planning	Port	1:Load	0.5	3	Week	0.06	1	M CM 2M	1	CE				
2.4	Voyage passage planning	Port	2:Unload	0.5	3	Week	0.03	1	M CM 2M	1	CE				
2.4	Voyage passage planning	OW	1:Normal	0.5	3	Week	0.27	1	M CM 2M	1	CE				
2.5	Weather monitoring, planning	Port	1:Load	0.5	2	Day	0.14	1	M CM 2M 3M RE						
2.5	Weather monitoring, planning	Port	2:Unload	0.5	2	Day	0.07	1	M CM 2M 3M RE						
2.5	Weather monitoring, planning	RW	1:Inbound/Outb	0.5	2	Day	0.17	1	M CM 2M 3M RE						
2.5	Weather monitoring, planning	OW	1:Normal	0.5	2	Day	0.62	1	M CM 2M 3M RE						
3	Communications							0		0		0		0	
3.1	Long range radio operations	Port	1:Load	0.3	1	Day	0.04	1	M CM REO						
3.1	Long range radio operations	Port	2:Unload	0.3	1	Day	0.02	1	M CM REO						
3.1	Long range radio operations	RW	1:Inbound/Outb	0.3	1	Day	0.05	1	M CM REO						
3.1	Long range radio operations	OW	1:Normal	0.3	1	Day	0.19	1	M CM REO						
3.2	Communication record keepin	RW	1:Inbound/Outb	0.2	2	Day	0.07	1	M CM 2M 3M RE						
3.2	Communication record keepin	OW	1:Normal	0.2	2	Day	0.25	1	M CM 2M 3M RE						
3.3	Sound & visual signaling	RW	1:Inbound/Outb	0.2	1	Week	0.01	1	CM 2M 3M	1	AB				
3.3	Sound & visual signaling	OW	1:Normal	0.2	1	Week	0.04	1	CM 2M 3M	1	AB				

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USCG CrewSEM – [Task-Crew Needs] (continued)

#	Task Name	Phase	Phase Type Description	Avg	Times	Per	Hrs/day Across Voyage	Req	Pool #1	Req	Pool #2	Req	Pool #3	Req	Pool #4
4.0	Engineering system M/C/O							0		0		0		0	
4.1	Engine M/C/O	Port	1:load	1	1	Hour	6.66	1	1AE 2AE 3AE	1	Q				
4.1	Engine M/C/O	Port	2:Unload	1	1	Hour	3.43	1	1AE 2AE 3AE	1	Q				
4.1	Engine M/C/O	RW	1:Inbound/Outb	1	1	Hour	12.00	1	CE	1	1AE 2AE 3 AE	1	Q		
4.1	Engine M/C/O	OW	1:Normal	1	1	Hour	29.71	1	1AE 2AE 3AE	1	Q				
4.2	Engineering rounds &record k	Port	1:Load	0.8	0.5	Hour	1.37	1	1AE 2AE 3AE Q						
4.2	Engineering rounds &record k	Port	2:Unload	0.8	0.5	Hour	0.69	1	1AE 2AE 3AE Q						
4.2	Engineering rounds &record k	RW	1:Inbound/Outb	0.8	0.5	Hour	1.60	1	1AE 2AE 3AE Q						
4.2	Engineering rounds &record k	OW	1:Normal	0.8	0.5	Hour	5.94	1	1AE 2AE 3AE Q						
4.5	Transfer fuel oil, diesel oil, & l	Port	1:Load	2.5	1	Week	0.10	1	1AE 2AE 3AE	1	Q				
4.5	Transfer fuel oil, diesel oil, & l	Port	2:Unload	2.5	1	Week	0.05	1	1AE 2AE 3AE	1	Q				
4.5	Transfer fuel oil, diesel oil, & l	RW	1:Inbound/Outb	2.5	1	Week	0.12	1	1AE 2AE 3AE	1	Q				
4.5	Transfer fuel oil, diesel oil, & l	Ow	1:Normal	2.5	1	Week	0.44	1	1AE 2AE 3AE	1	Q				
4.6	Bunkering	Port	2:Unload	5	1	Phase	1.43	1	CE	2	AB P B	1	1AE 2AE 3 AE		
5	Scheduled maintenance & tes							0		0		0		0	
5.1	Navigation equipment M/T	Port	1:Load	1	0.25	Week	0.01	1	CM 2M 3M 1AE						
5.1	Navigation equipment M/T	Port	2:Unload	1	0.25	Week	0.00	1	CM 2M 3M 1AE						
5.1	Navigation equipment M/T	OW	1:Normal	1	0.25	Week	0.02	1	CM 2M 3M 1AE						
5.2	Communication equipment M/	Port	1:Load	0.3	1	Week	0.01	1	CM 2M 3M 1AE						
5.2	Communication equipment M/	Port	2:Unload	0.3	1	Week	0.00	1	CM 2M 3M 1AE						
5.2	Communication equipment M/	RW	1:Inbound/Outb	0.3	1	Week	0.01	1	CM 2M 3M 1AE						
5.2	Communication equipment M/	OW	1:Normal	0.3	1	Week	0.03	1	CM 2M 3M 1AE						
5.3	Vessel fabric maintenance	OW	1:Normal	4	4	Week	5.66	1	B	3	AB P				
5.4	Cargo, deck, & hull equip. M/T	Port	1:Load	2	2	Week	0.33	1	B	3	AB P				
5.4	Cargo, deck, & hull equip. M/T	Port	2:Unload	2	2	Week	0.16	1	B	3	AB P				
5.4	Cargo, deck, & hull equip. M/T	OW	1:Normal	2	2	Week	1.41	1	B	3	AB P				
5.5	Firefighting equipment M/T	Port	1:Load	1.5	1	Week	0.03	1	3M						
5.5	Firefighting equipment M/T	Port	2:Unload	1.5	1	Week	0.02	1	3M						
5.5	Firefighting equipment M/T	OW	1:Normal	1.5	1	Week	0.13	1	3M						
5.6	Lifesaving equipment M/T	Port	1:Load	2	1	Week	0.04	1	3M						
5.6	Lifesaving equipment M/T	Port	2:Unload	2	1	Week	0.02	1	3M						
5.6	Lifesaving equipment M/T	OW	1:Normal	2	1	Week	0.18	1	3M						
5.7	Tools & test equipment M/T	OW	1:Normal	1	1	Week	0.18	1	1AE B	1	2AE 3AE AB P				
5.8	Plumbing M/T	OW	1:Normal	2	0.25	Week	0.09	1	1AE	1	2AE 3AE				

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USCG CrewSEM – [Task-Crew Needs] (continued)

#	Task Name	Phase	Phase Type Description	Avg	Times	Per	Hrs/day Across Voyage	Req	Pool #1	Req	Pool #2	Req	Pool #3	Req	Pool #4
5.9	Galley M/T	Port	1:Load	1.5	1	Week	0.03	1	1AE CS						
5.9	Galley M/T	Port	2:Unload	1.5	1	Week	0.02	1	1AE CS						
5.9	Galley M/T	RW	1:Inbound/Outb	1.5	1	Week	0.04	1	1AE CS						
5.9	Galley M/T	OW	1:Normal	1.5	1	Week	0.13	1	1AE CS						
5.10	Main engine M/T	Port	1:Load	2	2	Week	0.16	1	1AE 2AE 3AE	1	Q				
5.10	Main engine M/T	Port	2:Unload	2	2	Week	0.08	1	1AE 2AE 3AE	1	Q				
5.10	Main engine M/T	OW	1:Normal	2	2	Week	0.71	1	1AE 2AE 3AE	1	Q				
5.11	Boiler M/T	Port	1:Load	1	1	Day	0.29	1	1AE 2AE 3AE	1	Q				
5.11	Boiler M/T	Port	2:Unload	1	1	Day	0.14	1	1AE 2AE 3AE	1	Q				
5.11	Boiler M/T	OW	1:Normal	1	1	Day	1.24	1	1AE 2AE 3AE	1	Q				
5.12	Fuel oil system M/T	Port	1:Load	0.5	1	Day	0.14	1	1AE 2AE 3AE	1	Q				
5.12	Fuel oil system M/T	Port	2:Unload	0.5	1	Day	0.07	1	1AE 2AE 3AE	1	Q				
5.12	Fuel oil system M/T	RW	1:Inbound/Outb	0.5	1	Day	0.17	1	1AE 2AE 3AE	1	Q				
5.12	Fuel oil system M/T	OW	1:Normal	0.5	1	Day	0.62	1	1AE 2AE 3AE	1	Q				
5.13	Evaporator M/T	Port	1:Load	2	0.2	Week	0.02	1	1AE 2AE 3AE	1	Q				
5.13	Evaporator M/T	Port	2:Unload	2	0.2	Week	0.01	1	1AE 2AE 3AE	1	Q				
5.13	Evaporator M/T	OW	1:Normal	2	0.2	Week	0.07	1	1AE 2AE 3AE	1	Q				
5.14	Generator M/T	Port	1:Load	2	0.25	Week	0.02	1	1AE 2AE 3AE	1	Q				
5.14	Generator M/T	Port	2:Unload	2	0.25	Week	0.01	1	1AE 2AE 3AE	1	Q				
5.14	Generator M/T	OW	1:Normal	2	0.25	Week	0.09	1	1AE 2AE 3AE	1	Q				
5.15	Electrical system M/T	Port	1:Load	1	1	Week	0.02	1	1AE 2AE 3AE						
5.15	Electrical system M/T	Port	2:Unload	1	1	Week	0.01	1	1AE 2AE 3AE						
5.15	Electrical system M/T	OW	1:Normal	1	1	Week	0.09	1	1AE 2AE 3AE						
5.16	Pump M/T	Port	1:Load	2	0.5	Week	0.02	1	P						
5.16	Pump M/T	Port	2:Unload	2	0.5	Week	0.01	1	P						
5.16	Pump M/T	OW	1:Normal	2	0.5	Week	0.09	1	P						
5.17	Piping M/T	Port	1:Load	4	0.5	Week	0.08	1	1AE P	1	2AE 3AE				
5.17	Piping M/T	Port	2:Unload	4	0.5	Week	0.04	1	1AE P	1	2AE 3AE				
5.17	Piping M/T	OW	1:Normal	4	0.5	Week	0.35	1	1AE P	1	2AE 3AE				
5.18	Steering gear M/T	Port	1:Load	4	0.25	Week	0.02	1	1AE 2AE 3AE						
5.18	Steering gear M/T	Port	2:Unload	4	0.25	Week	0.01	1	1AE 2AE 3AE						
5.18	Steering gear M/T	OW	1:Normal	4	0.25	Week	0.09	1	1AE 2AE 3AE						
5.19	Inert gas system M/T	OW	1:Normal	3	1.25	Week	0.33	1	P						
5.20	Engine systems fabric M/T	Port	1:Load	4	1	Week	0.16	2	Q W						

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USCG CrewSEM – [Task-Crew Needs] (continued)

#	Task Name	Phase	Phase Type Description	Avg	Times	Per	Hrs/day Across Voyage	Req	Pool #1	Req	Pool #2	Req	Pool #3	Req	Pool #4
5.20	Engine systems fabric M/T	Port	2:Unload	4	1	Week	0.08	2	Q W						
5.20	Engine systems fabric M/T	RW	1:Inbound/Outb	4	1	Week	0.192	2	Q W						
5.20	Engine systems fabric M/T	OW	1:Normal	4	1	Week	0.71	2	Q W						
5.21	Heating, ventilation & AC M/T	Port	1:Load	2	0.25	Week	0.01	1	1AE 2AE 3AE						
5.21	Heating, ventilation & AC M/T	Port	2:Unload	2	0.25	Week	0.01	1	1AE 2AE 3AE						
5.21	Heating, ventilation & AC M/T	RW	1:Inbound/Outb	2	0.25	Week	0.01	1	1AE 2AE 3AE						
5.21	Heating, ventilation & AC M/T	OW	1:Normal	2	0.25	Week	0.04	1	1AE 2AE 3AE						
5.22	Sewage system M/T	OW	1:Normal	3	0.25	Week	0.07	1	1AE 2AE 3AE						
5.23	Engine room cleaning	Port	1:Load	1	1	Day	0.14	1	Q W						
5.23	Engine room cleaning	Port	2:Unload	1	1	Day	0.07	1	Q W						
5.23	Engine room cleaning	RW	1:Inbound/Outb	1	1	Day	0.17	1	Q W						
5.23	Engine room cleaning	OW	1:Normal	1	1	Day	0.62	1	Q W						
6	Unscheduled maintenance &							0		0		0		0	
6.1	Navigation equipment repair	Port	1:Load	1	0.25	Week	0.01	1	CM 2M 3M						
6.1	Navigation equipment repair	Port	2:Unload	1	0.25	Week	0.00	1	CM 2M 3M						
6.1	Navigation equipment repair	OW	1:Normal	1	0.25	Week	0.02	1	CM 2M 3M						
6.2	Communication equipment re	Port	1:Load	1	0.25	Week	0.01	1	CM 2M 3M REO						
6.2	Communication equipment re	Port	2:Unload	1	0.25	Week	0.00	1	CM 2M 3M REO						
6.2	Communication equipment re	OW	1:Normal	1	0.25	Week	0.02	1	CM 2M 3M REO						
6.3	Vessel fabric repair	Port	1:Load	4	0.1	Week	0.03	1	CM 2M 3M REO						
6.3	Vessel fabric repair	Port	2:Unload	4	0.1	Week	0.02	1	B	3	AB P				
6.3	Vessel fabric repair	OW	1:Normal	4	0.1	Week	0.14	1	B	3	AB P				
6.4	Cargo, deck, & hull equipment	Port	1:Load	4	0.25	Week	0.12	1	CM	1	B	4	AB P		
6.4	Cargo, deck, & hull equipment	Port	2:Unload	4	0.25	Week	0.06	1	CM	1	B	4	AB P		
6.4	Cargo, deck, & hull equipment	RW	1:Inbound/Outb	4	0.25	Week	0.14	1	CM	1	B	4	AB P		
6.4	Cargo, deck, & hull equipment	OW	1:Normal	4	0.25	Week	0.53	1	CM	1	B	4	AB P		
6.5	Firefighting equipment repair	Port	1:Load	2	0.25	Week	0.02	1	CM 2M 3M	1	AB P B				
6.5	Firefighting equipment repair	Port	2:Unload	2	0.25	Week	0.01	1	CM 2M 3M	1	AB P B				
6.5	Firefighting equipment repair	RW	1:Inbound/Outb	2	0.25	Week	0.02	1	CM 2M 3M	1	AB P B				
6.5	Firefighting equipment repair	OW	1:Normal	2	0.25	Week	0.09	1	CM 2M 3M	1	AB P B				
6.6	Lifesaving equipment repair	Port	1:Load	1.5	0.08	Week	0.00	1	CM 2M 3M	1	AB B				
6.6	Lifesaving equipment repair	Port	2:Unload	1.5	0.08	Week	0.00	1	CM 2M 3M	1	AB B				
6.6	Lifesaving equipment repair	RW	1:Inbound/Outb	1.5	0.08	Week	0.01	1	CM 2M 3M	1	AB B				
6.6	Lifesaving equipment repair	OW	1:Normal	1.5	0.08	Week	0.02	1	CM 2M 3M	1	AB B				

	#	Task Name	Phase	Phase Type Description	Avg	Times	Per	Hrs/day Across Voyage	Req	Pool #1	Req	Pool #2	Req	Pool #3	Req	Pool #4
	6.7	Tools & test equipment repair	Port	1:Load	2	0.5	Week	0.04	1	1AE 2AE 3AE	1	AB B				
	6.7	Tools & test equipment repair	Port	2:Unload	2	0.5	Week	0.02	1	1AE 2AE 3AE	1	AB B				
	6.7	Tools & test equipment repair	RW	1:Inbound/Ourb	2	0.5	Week	0.5	1	1AE 2AE 3AE	1	AB B				
	6.7	Tools & test equipment repair	OW	1:Normal	1	0.5	Week	0.18	1	1AE 2AE 3AE	1	AB B				
	6.8	Plumbing repair	Port	1:Load	4	0.25	Week	0.02	1	1AE 2AE 3AE						
	6.8	Plumbing repair	Port	2:Unload	4	0.25	Week	0.01	1	1AE 2AE 3AE						
	6.8	Plumbing repair	RW	1:Inbound/Outb	4	0.25	Week	0.02	1	1AE 2AE 3AE						
	6.8	Plumbing repair	OW	1:Normal	4	0.25	Week	0.09	1	1AE 2AE 3AE						
	6.9	Galley repair	Port	1:Load	1.2	0.13	Week	0.00	1	1AE 2AE 3AE						
	6.9	Galley repair	Port	2:Unload	1.2	0.13	Week	0.00	1	1AE 2AE 3AE						
	6.9	Galley repair	RW	1:Inbound/Outb	1.2	0.13	Week	0.00	1	1AE 2AE 3AE						
	6.9	Galley repair	OW	1:Normal	1.2	0.13	Week	0.01	1	1AE 2AE 3AE						
	6.10	Main engine repair	Port	1:Load	3	0.13	Week	0.04	1	CE	2	1AE 2AE 3AE	2	Q W		
	6.10	Main engine repair	Port	2:Unload	3	0.13	Week	0.02	1	CE	2	1AE 2AE 3AE	2	Q W		
	6.10	Main engine repair	OW	1:Normal	3	0.13	Week	0.17	1	CE	2	1AE 2AE 3AE	2	Q W		
	6.11	Boiler repair	Port	1:Load	4	1	Week	0.16	1	1AE 2AE 3AE	1	Q W				
	6.11	Boiler repair	Port	2:Unload	4	1	Week	0.08	1	1AE 2AE 3AE	1	Q W				
	6.11	Boiler repair	OW	1:Normal	4	1	Week	0.71	1	1AE 2AE 3AE	1	Q W				
	6.12	Fuel oil systems repair	Port	1:Load	4	0.1	Week	0.02	1	1AE 2AE 3AE	2	Q W				
	6.12	Fuel oil systems repair	Port	2:Unload	4	0.1	Week	0.01	1	1AE 2AE 3AE	2	Q W				
	6.12	Fuel oil systems repair	OW	1:Normal	4	0.1	Week	0.11	1	1AE 2AE 3AE	2	Q W				
	6.13	Evaporator repair	Port	1:Load	6	0.1	Week	0.02	1	1AE 2AE 3AE	1	Q W				
	6.13	Evaporator repair	Port	2:Unload	6	0.1	Week	0.01	1	1AE 2AE 3AE	1	Q W				
	6.13	Evaporator repair	OW	1:Normal	6	0.1	Week	0.11	1	1AE 2AE 3AE	1	Q W				
	6.14	Generator repair	Port	1:Load	6	0.03	Week	0.01	1	1AE	1	2AE 3AE	2	Q W		
	6.14	Generator repair	Port	2:Unload	6	0.03	Week	0.01	1	1AE	1	2AE 3AE	2	Q W		
	6.14	Generator repair	OW	1:Normal	6	0.03	Week	0.06	1	1AE	1	2AE 3AE	2	Q W		
	6.15	Electrical system repair	Port	1:Load	4	1	Week	0.08	1	1AE 2AE 3AE						
	6.15	Electrical system repair	Port	2:Unload	4	1	Week	0.04	1	1AE 2AE 3AE						
	6.15	Electrical system repair	RW	1:Inbound/Outb	4	1	Week	0.10	1	1AE 2AE 3AE						
	6.15	Electrical system repair	OW	1:Normal	4	1	Week	0.35	1	1AE 2AE 3AE						
	6.16	Pump repair	Port	1:Load	4	0.25	Week	0.04	1	1AE 2AE 3AE	1	Q W				
	6.16	Pump repair	Port	2:Unload	4	0.25	Week	0.02	1	1AE 2AE 3AE	1	Q W				
	6.16	Pump repair	RW	1:Inbound/Outb	4	0.25	Week	0.05	1	1AE 2AE 3AE	1	Q W				

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USCG CrewSEM – [Task-Crew Needs] (continued)

#	Task Name	Phase	Phase Type Description	Avg	Times	Per	Hrs/day Across Voyage	Req	Pool #1	Req	Pool #2	Req	Pool #3	Req	Pool #4
6.16	Pump repair	OW	1:Normal	4	0.25	Week	0.18	1	1AE 2AE 3AE	1	Q W				
6.17	Piping repair	Port	1:Load	2	0.5	Week	0.04	1	1AE 2AE 3AE	1	Q W				
6.17	Piping repair	Port	2:Unload	2	0.5	Week	0.02	1	1AE 2AE 3AE	1	Q W				
6.17	Piping repair	RW	1:Inbound/Outb	2	0.5	Week	0.05	1	1AE 2AE 3AE	1	Q W				
6.17	Piping repair	OW	1:Normal	2	0.5	Week	0.18	1	1AE 2AE 3AE	1	Q W				
6.18	Steering gear repair	Port	1:Load	3	0.1	Week	0.02	1	1AE	1	2AE 3AE	1	CE		
6.18	Steering gear repair	Port	2:Unload	3	0.1	Week	0.01	1	1AE	1	2AE 3AE	1	CE		
6.18	Steering gear repair	OW	1:Normal	3	0.1	Week	0.08	1	1AE	1	2AE 3AE	1	CE		
6.19	Inert gas repair	Port	1:Load	2	0.25	Week	0.02	1	1AE 2AE 3AE	1	P B				
6.19	Inert gas repair	Port	2:Unload	2	0.25	Week	0.01		1AE 2AE 3AE	1	P B				
6.19	Inert gas repair	RW	1:Inbound/Outb	2	0.25	Week	0.02	1	1AE 2AE 3AE	1	P B				
6.19	Inert gas repair	OW	1:Normal	2	0.25	Week	0.09	1	1AE 2AE 3AE	1	P B				
6.20	Engine systems fabric re	Port	1:Load	4	2	Week	0.33	2	Q W						
6.20	Engine systems fabric re	Port	2:Unload	4	2	Week	0.16	2	Q W						
6.20	Engine systems fabric re	RW	1:Inbound/Outb	4	2	Week	0.38	2	Q W						
6.20	Engine systems fabric re	OW	1:Normal	4	2	Week	1.41	2	Q W						
6.21	Heating, ventilation & AC	Port	1:Load	3	0.25	Week	0.03	1	CE 1AE'	1	Q W				
6.21	Heating, ventilation & AC	Port	2:Unload	3	0.25	Week	0.02	1	CE 1AE	1	Q W				
6.21	Heating, ventilation & AC	OW	1:Normal	3	0.25	Week	0.13	1	CE 1AE	1	Q W				
6.22	Sewage system repair	Port	1:Load	2	0.05	Week	0.00	2	1AE 2AE 3AE						
6.22	Sewage system repair	Port	2:Unload	2	0.05	Week	0.00	2	1AE 2AE 3AE						
6.22	Sewage system repair	OW	1:Normal	2	0.05	Week	0.02	2	1AE 2AE 3AE						
7	Emergency response							0		0		0		0	
8	Training & drills							0		0		0		0	
8.1	Navigation training	Port	2:Unolad	0.8	2	Week	0.03	2	CM 2M 3M						
8.1	Navigation training	RW	1:Inbound/Outb	0.8	2	Week	0.08	2	CM 2M 3M						
8.1	Navigation training	OW	1:Normal	0.8	2	Week	0.28	2	CM 2M #m						
8.2	Engine systems training	Port	1:Load	1.5	1	Week	0.06	1	CE	1	1AE				
8.2	Engine systems training	Port	2:Unload	1.5	1	Week	0.03	1	CE	1	1AE				
8.2	Engine systems training	RW	1:Inbound/Outb	1.5	1	Week	0.07	1	CE	1	1AE				
8.2	Engine systems training	OW	1:Normal	1.5	1	Week	0.27	1	CE	1	1AE				
8.3	Navigation emergency d	OW	1:Normal	0.8	0.25	Week	0.04	1	M	1	CM 2M 3M				
8.4	Communication systems	OW	1:Normal	0.1	0.25	Week	0.01	1	1AE	1	CE	1	2ae 3ae		
8.5	Engine room emergency	OW	1:Normal	1	0.04	Week	0.02	1	CE	3	1AE 2AE 3AE	3	Q		

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USCG CrewSEM – [Task-Crew Needs] (continued)

#	Task Name	Phase	Phase Type Description	Avg	Times	Per	Hrs/day Across Voyage	Req	Pool #1	Req	Pool #2	Req	Pool #3	Req	Pool #4
8.6	Fire & lifeboat drills	OW	1:Normal	1	1	Week	2.12	24	M CM 2M 3M CE						
8.7	Man overboard drill	OW	1:Normal	1.5	0.25	Week	0.80	24	M CM 2M 3M CE						
8.8	Oil spill response drills	Port	1:Load	1	0.25	Week	0.01	1	M CM 2M 3M CE						
8.8	Oil spill response drills	OW	1:Normal	1	0.25	Week	0.02	1	M CM 2M 3M CE						
9	Management & administration							0		0		0		0	
9.1	Deck work schedule managen	Port	1:Load	2	1	Day	0.57	1	M CM	1	B				
9.1	Deck work schedule managen	Port	2:Unload	2	1	Day	0.29	1	M CM	1	B				
9.1	Deck work schedule managen	RW	1:Inbound/Outb	2	1	Day	0.67	1	M CM	1	B				
9.1	Deck work schedule managen	OW	1:Normal	2	1	Day	2.48	1	M CM	1	B				
9.2	Chart records & corrections	Port	1:Load	1	1	Week	0.02	1	2M						
9.2	Chart records & corrections	Port	2:Unload	1	1	Week	0.01	1	2M						
9.2	Chart records & corrections	OW	1:Normal	1	1	Week	0.09	1	2M						
9.3	Sign-on/sign-off crew member	Port	1:Load	1	1	Phase	0.14	1	M CM						
9.3	Sign-on/sign-off crew member	Port	2:Unload	1	1	Phase	0.07	1	M CM						
9.4	Financial & payroll transaction	Port	1:Load	1	2	Week	0.12	1	M	1	CE	1	CS		
9.4	Financial & payroll transaction	Port	2:Unload	1	2	Week	0.06	1	M	1	CE	1	CS		
9.4	Financial & payroll transaction	OW	1:Normal	1	2	Week	0.53	1	M	1	CE	1	CS		
9.5	Deck stores & supplies	Port	2:Unload	2	1	Phase	0.71	1	CM	1	B	3	AB		
9.6	Drill record keeping & reportin	Port	1:Load	0.3	1	Week	0.01	1	3M						
9.6	Drill record keeping & reportin	Port	2:Unload	0.3	1	Week	0.00	1	3M						
9.6	Drill record keeping & reportin	RW	1:Inbound/Outb	0.3	1	Week	0.01	1	3M						
9.6	Drill record keeping & reportin	OW	1:Normal	0.3	1	Week	0.03	1	3M						
9.7	Ship yard planning	Port	1:Load	1	0.25	Week	0.02	1	M	1	CM	1	CE		
9.7	Ship yard planning	Port	2:Unload	1	0.25	Week	0.01	1	M	1	CM	1	CE		
9.7	Ship yard planning	RW	1:Inbound/Outb	1	0.25	Week	0.02	1	M	1	CM	1	CE		
9.7	Ship yard planning	OW	1:Normal	1	0.25	Week	0.07	1	M	1	CM	1	CE		
9.9	Engine room work & schedule	Port	1:Load	0.3	1	Day	0.09	1	CE	1	1AE				
9.9	Engine room work & schedule	Port	2:Unload	0.3	1	Day	0.04	1	CE	1	1AE				
9.9	Engine room work & schedule	OW	1:Normal	0.3	1	Day	0.37	1	CE	1	1AE				
9.10	Engine room stores	Port	1:Load	2	0.25	Week	0.03	1	1AE 2AE 3AE	2	Q W				
9.10	Engine room stores	Port	2:Unload	2	0.25	Week	0.02	1	1AE 2AE 3AE	2	Q W				
9.11	Medical record keeping, loggir	Port	1:Load	1	1	Week	0.02	1	M 2M						
9.11	Medical record keeping, loggir	Port	2:Unload	1	1	Week	0.01	1	M 2M						
9.11	Medical record keeping, loggir	OW	1:Normal	1	1	Week	0.09	1	M 2M						

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USCG CrewSEM – [Task-Crew Needs] (continued)

#	Task Name	Phase	Phase Type Description	Avg	Times	Per	Hrs/day Across Voyage	Req	Pool #1	Req	Pool #2	Req	Pool #3	Req	Pool #4
9.12	Medical care	Port	1:Load	1	0.5	Week	0.01	1	M CM 2M						
9.12	Medical care	Port	2:Unload	1	0.5	Week	0.01	1	M CM 2M						
9.12	Medical care	RW	1:Inbound/Outb	1	0.5	Week	0.01	1	M CM 2M						
9.12	Medical care	OW	1:Normal	1	0.5	Week	0.04	1	M CM 2M						
10	Internal ship communications							0		0		0		0	
10.1	Labor relations	Port	1:Load	0.3	1	Week	0.02	1	M	1	CM	1	CS	1	CE
10.1	Labor relations	Port	2:Unload	0.3	1	Week	0.01	1	M	1	CM	1	CS	1	CE
10.1	Labor relations	OW	1:Normal	0.3	1	Week	0.11	1	M	1	CM	1	CS	1	CE
10.2	Shipboard management meeti	OW	1:Normal	0.5	1	Week	0.18	1	M	1	CM	1	CE	1	1AE
10.3	Safety meetings	OW	1:Normal	1	0.25	Week	0.02	1	M CM 2M 3M CE						
10.4	Quality of work life meetings	OW	1:Normal	0.9	0.25	Week	0.04	1	M	1	CE				
10.5	Continuing education & profes	OW	1:Normal	1	0.25	Week	0.04	1	M	1	CM 2M 3M				
10.6	Promotion, retention & career	OW	1:Normal	1	0.25	Week	0.07	1	M	1	CM 2M 3M				
11	Regulatory compliance							0		0		0		0	
11.1	Deck pollution prevention com	Port	1:Load	1	2	Week	0.24	1	M	4	AB P B	1	CM		
11.1	Deck pollution prevention com	Port	2:Unload	1	2	Week	0.12	1	M	4	AB P B	1	CM		
11.1	Deck pollution prevention com	OW	1:Normal	1	2	Week	1.06	1	M	4	AB P B	1	CM		
11.2	Engine room pollution prevent	Port	1:Load	0.8	2	Week	0.07	1	CE 1AE 2AE 3AE	1	Q				
11.2	Engine room pollution prevent	Port	2:Unload	0.8	2	Week	0.03	1	CE 1AE 2AE 3AE	1	Q				
11.2	Engine room pollution prevent	OW	1:Normal	0.8	2	Week	0.28	1	CE 1AE 2AE 3AE	1	Q				
11.3	Documentation & certification	Port	1:Load	0.5	0.2	Week	0.00	1	M CM	1	CE				
11.3	Documentation & certification	Port	2:Unload	0.5	0.2	Week	0.00	1	M CM	1	CE				
11.3	Documentation & certification	OW	1:Normal	0.5	0.2	Week	0.02	1	M CM	1	CE				
11.4	Regulatory pubs & manageme	OW	1:Normal	1	0.5	Week	0.04	1	CM						
11.5	Pre-sail testing/fitness for duty	Port	1:Load	0.2	2	Week	0.01	1	M						
11.5	Pre-sail testing/fitness for duty	Port	2:Unload	0.2	2	Week	0.00	1	M						
11.6	Communication equipment, G	Port	1:Load	0.1	1	Day	0.01	1	CM 2M 3M						
11.6	Communication equipment, G	Port	2:Unload	0.1	1	Day	0.01	1	CM 2M 3M						
11.6	Communication equipment, G	RW	1:Inbound/Outb	0.1	1	Day	0.02	1	CM 2M 3M						
11.6	Communication equipment, G	OW	1:Normal	0.1	1	Day	0.06	1	CM 2M 3M						
11.7	Fire & safety inspections	Port	1:Load	1	1	Week	0.02	1	CM 2M 3M AB B						
11.7	Fire & safety inspections	Port	2:Unload	1	1	Week	0.01	1	CM 2M 3M AB B						
11.7	Fire & safety inspections	OW	1:Normal	1	1	Week	0.09	1	CM 2M 3M AB B						
11.8	Sanitary inspections	Port	1:Load	0.5	1	Week	0.02	1	M CM 2M 3M	1	CS				

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USCG CrewSEM – [Task-Crew Needs] (continued)

#	Task Name	Phase	Phase Type Description	Avg	Times	Per	Hrs/day Across Voyage	Req	Pool #1	Req	Pool #2	Req	Pool #3	Req	Pool #4
11.8	Sanitary inspections	Port	2:Unload	0.5	1	Week	0.01	1	M CM 2M 3M	1	CS				
11.8	Sanitary inspections	OW	1:Normal	0.5	1	Week	0.09	1	M CM 2M 3M	1	CS				
11.9	Inspection planning	OW	1:Normal	0.5	1	Week	0.18	1	M	1	CM	1	CE	1	CS
12	Cargo responsibilities & passe							0		0		0		0	
12.1	Cargo planning	OW	1:Normal	1.3	1	Phase	0.37	1	CM	1	P				
12.2	Cargo load/discharge prepara	Port	1:Load	0.3	1	Phase	0.13	1	CM	2	P				
12.2	Cargo load/discharge prepara	Port	2:Unload	0.3	1	Phase	0.06	1	CM	2	P				
12.3	Cargo equipment test	Port	1:Load	1	1	Phase	0.43	1	CM	1	2M 3M	1	AB P B		
12.3	Cargo equipment test	Port	2:Unload	1	1	Phase	0.21	1	CM	1	2M 3M	1	AB P B		
12.4	Cargo loading	Port	1:Load	15	1	Phase	8.57	1	CM LM	1	CM 2M 3M	2	AB P B		
12.5	Cargo unloading	Port	2:Unload	15	1	Phase	4.29	1	CM LM	1	CM 2M 3M	2	AB P B		
12.6	Cargo maintenance	OW	1:Normal	0.8	1	Day	0.99	1	CM p	1	2M 3M				
12.7	Cargo monitoring & record ke	Port	1:Load	1.5	1	Week	0.03	1	CM p						
12.7	Cargo monitoring & record ke	Port	2:Unload	1.5	1	Week	0.02	1	CM p						
12.7	Cargo monitoring & record ke	OW	1:Normal	1.5	1	Week	0.13	1	CM p						
12.10	Tank cleaning	Port	1:Load	8	0.5	Week	0.49	1	CM	1	2M 3M	1	B	3	AB P
12.10	Tank cleaning	OW	1:Normal	8	0.5	Week	2.12	1	CM	1	2M 3M	1	B	3	AB P
12.11	Ballast loading	Port	1:Load	1.5	1	Phase	0.43	1	1AE 2AE 3AE	1	P Q				
12.11	Ballast loading	Port	2:Unload	1.5	1	Phase	0.21	1	1AE 2AE 3AE	1	P Q				
12.11	Ballast loading	RW	1:Inbound/Outb	1	1	Phase	0.57	1	1AE 2AE 3AE	1	P Q				
12.11	Ballast loading	OW	1:Normal	1	1	Day	1.24	1	1AE 2AE 3AE	1	P Q				
12.12	Ballast discharge or transfer	Port	1:Load	1	1	Phase	0.29	1	1AE 2AE 3AE	1	P Q				
12.12	Ballast discharge or transfer	Port	2:Unload	1	1	Phase	0.14	1	1AE 2AE 3AE	1	P Q				
12.12	Ballast discharge or transfer	RW	1:Inbound/Outb	1	1	Phase	0.57	1	1AE 2AE 3AE	1	P Q				
12.12	Ballast discharge or transfer	OW	1:Normal	1	1	Phase	0.29	1	1AE 2AE 3AE	1	P Q				
12.13	Ballast maintenance & soundi	Port	1:Load	1	1	Week	0.04	1	1AE 2AE 3AE	1	P Q				
12.13	Ballast maintenance & soundi	Port	2:Unload	1	1	Week	0.02	1	1AE 2AE 3AE	1	P Q				
12.13	Ballast maintenance & soundi	OW	1:Normal	1	1	Week	0.18	1	1AE 2AE 3AE	1	P Q				
12.14	Stability monitoring & calculati	Port	1:Load	1	1	Phase	0.29	1	M	1	CM				
12.14	Stability monitoring & calculati	Port	2:Unload	1	1	Phase	0.14	1	M	1	CM				
13	Hotel services							0		0		0		0	
13.1	Hotel services administration	Port	1:Load	1	1	Day	0.14	1	CS						
13.1	Hotel services administration	Port	2:Unload	1	1	Day	0.07	1	CS						
13.1	Hotel services administration	RW	1:Inbound/Outbou	1	1	Day	0.17	1	CS						

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USCG CrewSEM – [Task-Crew Needs] (continued)

#	Task Name	Phase	Phase Type Description	Avg	Times	Per	Hrs/day Across Voyage	Req	Pool #1	Req	Pool #2	Req	Pool #3	Req	Pool #4
13.1	Hotel services administration	OW	1:Normal	1	1	Day	0.62	1	CS						
13.2	Food preparation	Port	1:Load	2	2	Day	1.14	1	C	1	C CS				
13.2	Food preparation	Port	2:Unload	2	2	Day	0.57	1	C	1	C CS				
13.2	Food preparation	RW	1:Inbound/Outb	2	2	Day	1.33	1	C	1	C CS				
13.2	Food preparation	OW	1:Normal	2	2	Day	4.95	1	C	1	C CS				
13.3	Food service	Port	1:Load	1	3	Day	1.29	3	U C CS						
13.3	Food service	Port	2:Unload	1	3	Day	0.64	3	U C CS						
13.3	Food service	RW	1:Inbound/Outb	1	3	Day	1.50	3	U C CS						
13.3	Food service	OW	1:Normal	1	3	Day	5.57	3	U C CS						
13.4	Galley & mess room cleaning	Port	1:Load	2	1	Day	0.86	3	U C CS						
13.4	Galley & mess room cleaning	Port	2:Unload	2	1	Day	0.43	3	U C CS						
13.4	Galley & mess room cleaning	RW	1:Inbound/Outb	2	1	Day	1.00	3	U C CS						
13.4	Galley & mess room cleaning	RW	1:Normal	2	1	Day	3.71	3	U C CS						
13.5	Bridge, accommodation, & spa	Port	1:Load	1.5	1	Day	0.21	1	U						
13.5	Bridge, accommodation, & spa	Port	2:Unload	1.5	1	Day	0.11	1	U						
13.5	Bridge, accommodation, & spa	RW	1:Inbound/Outb	1.5	1	Day	0.25	1	U						
13.5	Bridge, accommodation, & spa	OW	1:Normal	1.5	1	Day	0.93	1	U						
13.6	Provisioning & provisioning ma	Port	1:Load	2	2	Week	0.16	1	CS	1	U C				
13.6	Provisioning & provisioning ma	Port	2:Unload	2	2	Week	0.08	1	CS	1	U C				
13.6	Provisioning & provisioning ma	OW	1:Normal	2	2	Week	0.71	1	CS	1	U C				
13.7	Galley stores & supplies	Port	2:Unload	2	0.5	Week	0.03	1	C CS	2	AB U B				
13.8	Recreation	OW	1:Normal	0.8	1	Week	0.07	1	M CS						
14	Arrival, departure, & port watc							0		0		0		0	
14.1	Departure prep. & testing	Port	1:Load	0.8	1	Phase	0.80	1	2M 3M	1	1AE 2AE 3AE	1	CM	4	AB B
14.1	Departure testing	Port	2:Unload	0.8	1	Phase	0.40	1	2M 3M	1	1AE 2AE 3AE	1	CM	4	AB B
14.2	Arrival prep. & testing	RW	1:Inbound/Outb	0.8	1	Phase	1.60	1	2M 3M	1	1AE 2AE 3AE	1	CM	4	AB B
14.2	Arrival prep. & testing	OW	1:Normal	0.8	1	Phase	0.80	1	2M 3M	1	1AE 2AE 3AE	1	CM	4	AB B
14.3	Escort vessel interaction/coord	RW	1:Inbound/Outb	0.5	1	Phase	0.43	1	2M 3M	2	AB B				
14.4	Docking	Port	1:Load	1.5	1	Phase	1.93	1	M	3	Cm 2M 3M	4	AB	1	B
14.4	Docking	Port	2:Unload	1.5	1	Phase	0.96	1	M	3	CM 2M 3M	4	AB	1	B
14.5	Undocking	Port	1:Load	1.5	1	Phase	1.93	1	M	3	CM 2M 3M 4	4	AB	1	B
14.5	Undocking	Port	2:Unload	1.5	1	Phase	0.96	1	M	3	CM 2M 3M	4	AB	1	B
14.10	Crane & tug operation	Port	1:Load	4	0.01	Week	0.00	1	B	3	AB				
14.11	Monitor vessel's lines & secur	Port	1:Load	1	1	Hour	6.86	2	AB						

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USCG CrewSEM – [Task-Crew Needs] (continued)

#	Task Name	Phase	Phase Type Description	Avg	Times	Per	Hrs/day Across Voyage	Req	Pool #1	Req	Pool #2	Req	Pool #3	Req	Pool #4
14.11	Monitor vessel's lines & secur	Port	2:Unload	1	1	Hour	3.43	2	AB						
14.12	Intrusion security watch opera	Port	1:Load	0.2	0.5	Hour	0.34	1	AB						
14.12	Intrusion security watch opera	Port	2:Unload	0.2	0.5	Hour	0.17	1	AB						
15	Special operational requireme							0		0		0		0	
9.8	Main engine record keeping-h	RW	1:Inbound/Outbou	0.5	1	Day	0.08	1	CE 1AE 2AE 3AE						
9.8	Main engine record keeping-h	OW	1:Normal	0.5	1	Day	0.31	1	CE 1AE 2AE 3AE						
11.10	Oversight inspection planning	OW	1:Normal	1	0.5	Week	0.13	1	M	1	CM	1	CE		

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Appendix D: ANOVA Tables

Below are the ANOVA tables for each of the three analyses performed (port call frequency, shoreside maintenance, and work/rest rules). η^2 is a standard measure of effect size: the larger it's value, the larger the effect size (Stevens, 1996).

Table D-1 summarizes the statistical analyses, showing that changes in port call frequency has a large effect on four of the five measures. The only exception is task delay, which does not show a statistically significant effect of scenario (port call frequency). The strong interaction indicates that the influence of port calls is not uniform across the crew. For example, port call frequency has a relatively small effect on Utility persons, but a large affect on the Mates and ABs.

Table D-1. Summary of Statistical Analyses of Port Call Frequency.[4]

Variable	Crew types ©	Scenario (S)	Interaction (CXS)
Work	$F(9,162)=187.2$ $p<0.001$, $\eta^2=0.91$	$F(2,18)=56.6$ $p<0.001$, $\eta^2=0.86$	$F(18,162)=22.8$ $p<0.001$, $\eta^2=0.72$
WGTE18	$F(9,162)=30.3$, $p<0.001$, $\eta^2=0.63$	$F(2,18)=14.6$ $p<0.001$, $\eta^2=0.62$	$F(18,162)=6.9$ $p<0.001$, $\eta^2=0.44$
Busy	$F(9,162)=97.4$, $p<0.001$, $\eta^2=0.84$	$F(2,18)=26.0$ $p<0.001$, $\eta^2=0.74$	$F(18,162)=17.9$ $p<0.001$, $\eta^2=0.67$
D_OPA90	$F(9,162)=64.9$, $p<0.001$, $\eta^2=0.78$	$F(2,18)=10.8$ $p<0.001$, $\eta^2=0.54$	$F(18,162)=11.7$ $p<0.001$, $\eta^2=0.57$
Delay	$F(9,162)=73.8$, $p<0.001$, $\eta^2=0.80$	$F(2,18)=4.97$, N.S. $\eta^2=0.36$	$F(18,162)=10.2$ $p<0.001$, $\eta^2=0.53$

[4] η^2 is a standard measure of effect size. The larger its value, the larger the effect size (Stevens, 1996).

Table D-2 summarizes the statistical analyses, showing that changes in the level of shore-based maintenance have a significant effect on three of the five measures, with WGTE18 and Delay being unaffected. The strong interaction indicates that the influence of shore-based maintenance is not uniform across the crew. Specifically, the interaction shows that the level of shore-based maintenance has the greatest effect on specific crew types, such as the Assistant Engineers, the Boatswain, and the Pumpmen.

Table D-2. Summary of Statistical Analyses of Shore-based Maintenance Support.

Variable	Crew types ©	Scenario (S)	Interaction (CXS)
Work	$F(9,378)=847.6$ $p<0.001$, $\eta^2=0.95$	$F(6,42)=4.8$ $p<0.001$, $\eta^2=0.41$	$F(54,378)=3.81$ $p<0.001$, $\eta^2=0.35$
WGTE18	$F(9,378)=98.1$ $p<0.001$, $\eta^2=0.70$	$F(6,42)=1.36$ N.S., $\eta^2=0.16$	$F(54,378)=0.55$ N.S., $\eta^2=0.07$
Busy	$F(9,378)=1009.2$ $p<0.001$, $\eta^2=0.96$	$F(6,42)=5.9$ $p<0.001$, $\eta^2=0.46$	$F(54,378)=7.5$ $p<0.001$, $\eta^2=0.52$
D_OPA90	$F(9,378)=322.5$ $p<0.001$, $\eta^2=0.89$	$F(6,42)=3.15$ $p<0.01$, $\eta^2=0.31$	$F(54,378)=4.0$ $p<0.001$, $\eta^2=0.37$
Delay	$F(9,378)=252.3$ $p<0.001$, $\eta^2=0.86$	$F(6,42)=1.44$ N.S., $\eta^2=0.17$	$F(54,378)=0.89$ N.S., $\eta^2=0.11$

Table D-3 summarizes the statistical analyses, showing that different work/rest standards have a large and significant effect on the hours worked, the number of nonconformances, and the time spent occupied with tasks. The effect of the standards does not reach statistical significance for the percent of days over 18 hours or for task delays. The moderate interaction indicates that the effect is not uniform over the crew. The different work/rest standards have a particularly large effect on the Master and the ABs.

Table D-3. Summary of Statistical Analyses of Different Work/Rest Standards.

Variable	Crew types ©	Scenario (S)	Interaction (CXS)
Work	$F(9,216)=390.2$ $p<0.001$, $\eta^2=0.94$	$F(3,42)=42.5$ $p<0.001$, $\eta^2=0.84$	$F(54,378)=3.81$ $P<0.001$, $\eta^2=0.35$
WGTE18	$F(9,216)=48.2$ $p<0.001$, $\eta^2=0.67$	$F(3,42)=4.3$ N.S., $\eta^2=0.35$ N.S.	$F(54,378)=0.55$ N.S., $\eta^2=0.07$ N.S.
Busy	$F(9,216)=210.8$ $p<0.001$, $\eta^2=0.90$	$F(3,42)=59.5$ $p<0.001$, $\eta^2=0.88$	$F(54,378)=7.5$ $p<0.001$, $\eta^2=0.52$
Nonconformance	$F(9,216)=185.1$ $p<0.001$, $\eta^2=0.89$	$F(3.42)=89.8$ $p<0.001$, $\eta^2=0.92$	$F(54,378)=4.0$ $p<0.001$, $\eta^2=0.37$
Delay	$F(9,216)=84.6$ $p<0.001$, $\eta^2=0.78$	$F(3,42)=3.8$ N.S., $\eta^2=0.326$ N.S	$F(54,378)=0.89$ N.S., $\eta^2=0..11$ N.S

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